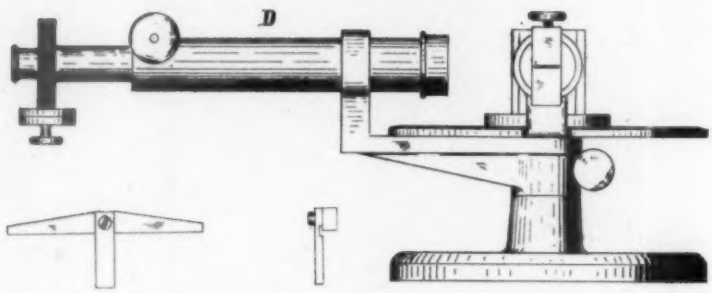


Fig 2 A

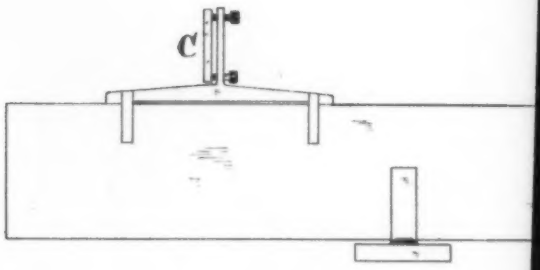
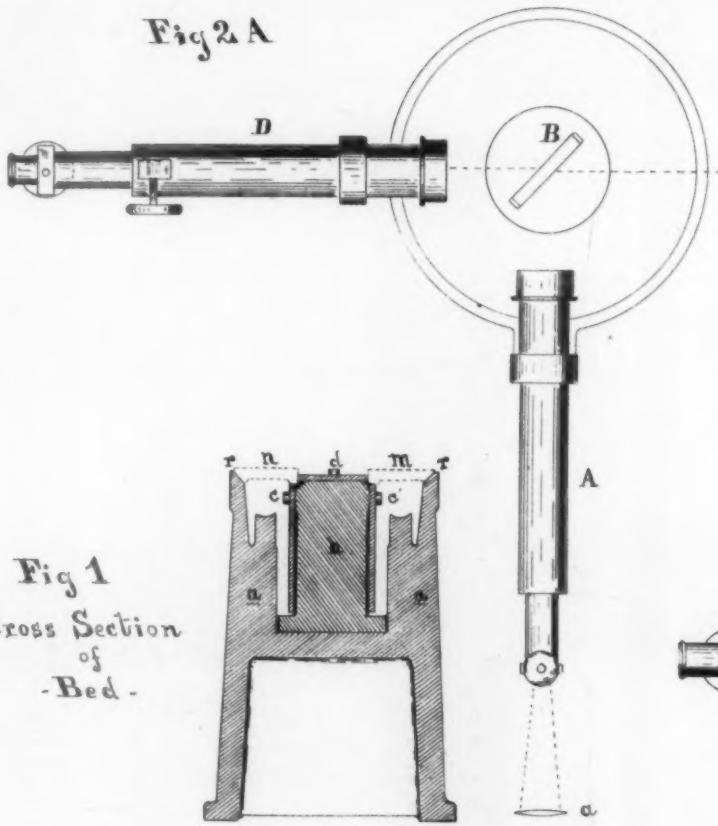


Fig. 2



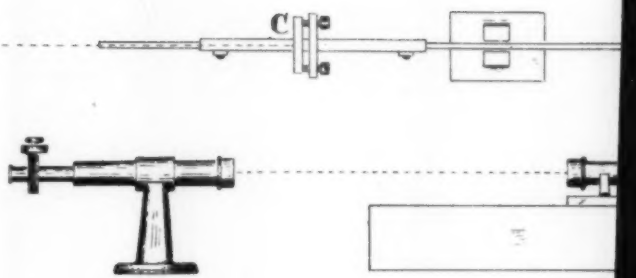


Fig. 1

Fig 1
Cross Section
of
-Bed-

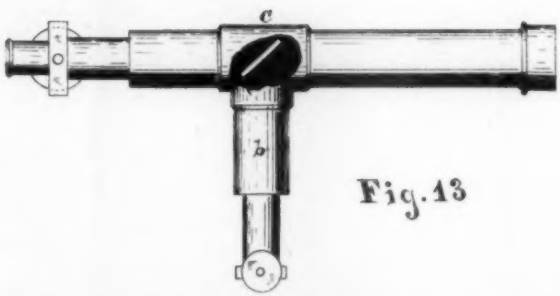


Fig. 13

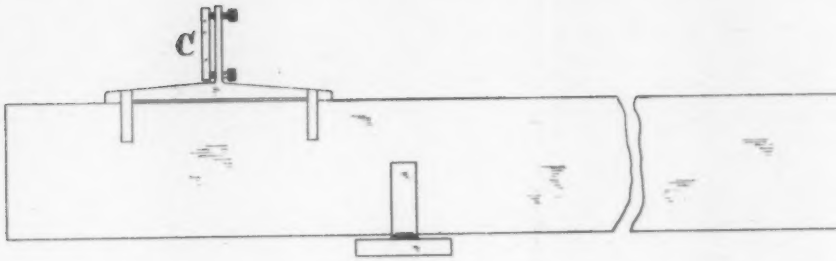


Fig. 2

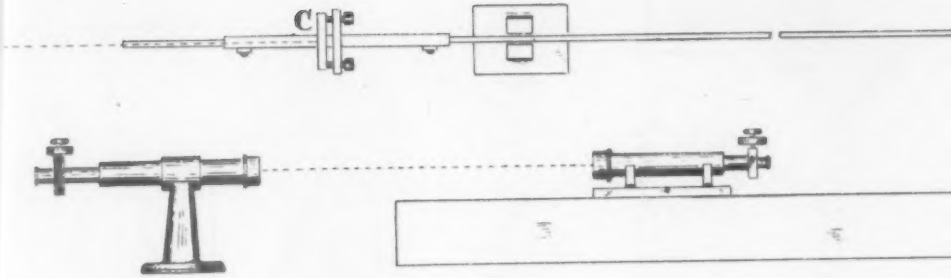


Fig. 14

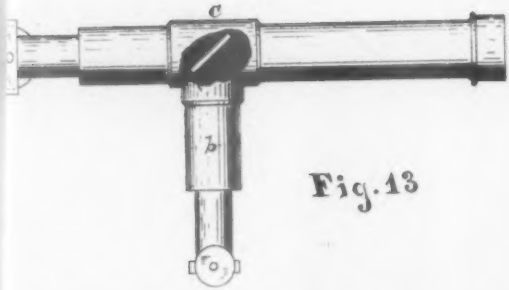
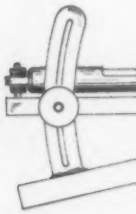


Fig. 13



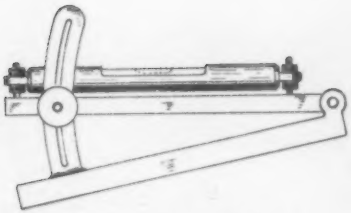


Fig. 15

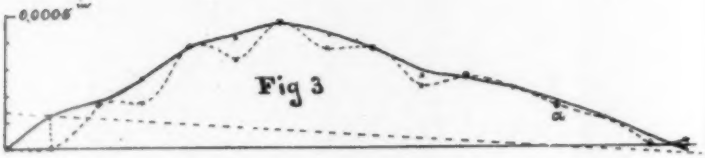


Fig 3

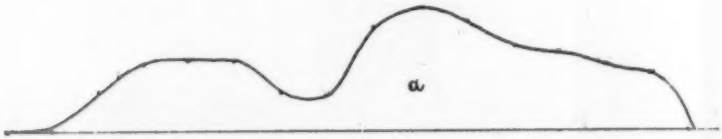


Fig 4

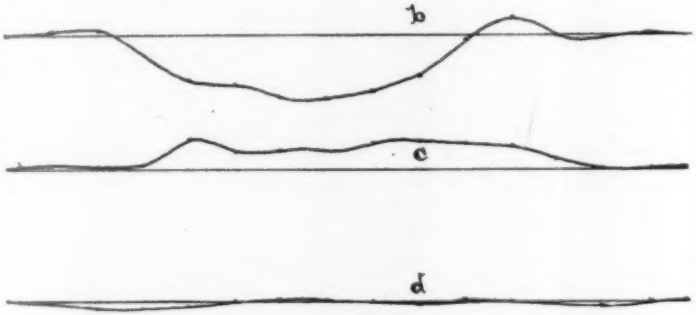


Fig 5

Fig 6

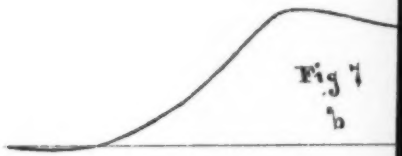


Fig 7

Fig 8

Fig 9

Fig 10

Fig 11

Fig 12

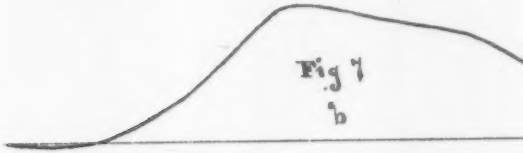


Fig 7

Fig 8

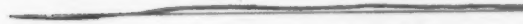


Fig 9

Fig 10

Fig 11

Fig 12

9
10
11
12

JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXXXVIII. JULY, 1894. NO. 1

THE Franklin Institute is not responsible for the statements and opinions advanced by contributors to the *Journal.*

THE MANUFACTURE OF VERY ACCURATE STRAIGHT EDGES.

BY F. L. O. WADSWORTH.

In the construction of mechanical or scientific instruments of precision, the problem frequently arises to provide means of guiding carriages through a considerable distance in as straight a line as possible.

Rectilinear motion may in general be secured by the employment of either link work or by the use of gibs or ways; but of these two methods the latter is by far the one more frequently adopted.

In the construction of the large "wave comparer," which has recently been used with such great success by Professor Michelson in his determination of the standard meter in

terms of the wave length of light,* this same problem was presented, and the accuracy of movement demanded was considerably greater than is usually attained, even in the best comparators and measuring machines.

In this case the employment of link work was rendered impossible on account of the limited space at disposal, even granting that its employment would have secured the desired accuracy. The use of planed ways on the bed of the instrument itself, which in its general features resembled a long lathe bed, was equally inadmissible, because even if such ways could once be brought to the degree of straightness demanded, the initial strains in the casting would soon manifest themselves to such a degree as to render a resurfacing, or rather a restraightening, of the ways necessary whenever the bed was moved. For these and other reasons it was finally determined to secure the desired accuracy of movement by the use of steel straight edges as guides for the carriages; these straight edges forming no part of the bed itself, and being secured to it in such a way as to avoid as far as possible any distortion from a twisting or warping of the support.

The manner in which this was done is shown in *Fig. 1*, which shows the bed in cross-section. The main portion of the bed *a a* is of H section, and has planed upon it two ways *r r*, on which the outer edges of the two carriages *M N* rest and slide. On the central cross bar of the H rests a long cast-iron bar *b*, against which are lightly clamped the three steel blades *c c' d*, four edges of which, viz.: the two edges of the horizontal blade and the two upper edges of the two vertical blades, form the inner ways for the carriages *M*, *N*, which move longitudinally along the bed, and are therefore guided in their movement by the two planed ways *r r* on the bed and the steel straight edges just referred to, the carriages being kept against the two vertical edges of *d* by the action of the inclined ways *r r*.

The actual problem was not, as might have been inferred

* *Nature*, **49**, 60.

from the preliminary statement of it, to have every point in the carriage move in a straight line; this would have necessitated that the outer ways *r r* be of the same order of accuracy as the straight edges, and this even if once secured would have been extremely difficult to preserve; but it was to have the carriage so guided that the plane of section perpendicular to the line of movement should always remain parallel to a given fixed plane, or in practice so that a mirror supported on the carriage with its face in this plane should always remain as nearly as possible normal to a ray of light whose direction is parallel to the direction of movement.

Now, it is evident from this disposition and arrangement of bearing surfaces, that any irregularity or want of straightness in one of the ways *r r*, will produce simply a rotation of the carriage in a plane perpendicular to the line of intersection of the planes of the two edges, and that granting only that each of these edges be straight any surface mounted on the carriage parallel to this perpendicular plane will remain parallel to itself for all positions of the carriage. It is not necessary, either that the ways *r r* be straight or parallel to the straight edges, or that these last be parallel to one another.*

The problem, from a mechanical standpoint, then reduced itself to one of producing four straight edges, of such an order of accuracy that the extreme angular movement of the carriage in moving from one end to the other of its ways should not exceed two seconds (2″) of arc, which means in linear terms that the error in any part of the straight edge should not be greater than $\frac{1}{100000}$ the length of the carriage (in this case seven inches), or about $\frac{1}{15000}$ of an inch. Although this was a rather high degree of accuracy for such long straight edges (5$1\frac{1}{2}$ inches), it was hoped

*A slight error is introduced on account of the finite width of the edges themselves, and the finite length of the bearing points, the bearing surfaces on the carriages being each about fifteen millimeters long, and of a width equal to the thickness of the straight edge; but the errors introduced by this cause are of the second order, as compared with the necessary irregularities in the ways themselves.

that the manufacturers would be able to make them of the required degree of accuracy by ordinary mechanical processes. After considerable correspondence, the work was intrusted to a well-known Eastern firm, whose reputation for this class of work is unexcelled in either this country or in Europe. In order, however, to check the results obtained by the manufacturers, as well as to afford a means of testing the edges after they were secured in place and at any future time during the use of the instrument, it was necessary to devise a method by which the edges might be compared with another standard edge; such, for example, as an actual metal standard, or a mercury surface.

The construction of another standard especially for this purpose involved considerable expense, which it was desirable to avoid.

Besides, in order to insure that this reference standard itself retains its form to this degree of accuracy in all positions of its use, it would have been necessary to have made it too deep and stiff to have been conveniently used in the space between the vertical edges and the sides of the bed. The two horizontal edges, c, c', might have been compared with a mercury surface by the aid of a high-power microscope, a method used by Professor Rogers in surfacing the bed of the Rogers-Bond comparator, but it is difficult to devise any simple method for comparing a vertical edge with such a horizontal surface.

The method, proposed by Professor Michelson and used first in the process of examination and afterward, during the process of grinding, for measuring the errors of the edges and checking the grinding process, is an optical one, which has been found more convenient in practice and capable of giving more accurate results than the methods of this character which have heretofore been used. It is to the improved method of testing rather than to any improved method of working that the results which have been obtained are due, for in any method of working in which corrections are determined and applied with reference to a standard edge or standard surface, the accuracy of the result cannot, as a rule, exceed the accuracy of the standard.

In this case the reference edge, if such it may be called, which is used as a standard, is as near a geometrical straight line as it is possible to approach by any physical method, being what is termed a ray of light in the language of geometrical optics.

More explicitly stated, the method consists in projecting a parallel beam of light normally on the surface of a mirror, mounted on a carriage, which slides along the edge to be examined (the mirror being placed as nearly as possible at right angles to the edge), and measuring the angular deviation of the reflected beam as the carriage is moved along the straight edge.

The actual apparatus which was employed for the purpose is shown in *Fig. 2*. Light from the illuminated cross wires of an ordinary telescope focussed for parallel rays falls upon a plane parallel piece of glass *B*, by which a portion is reflected to the mirror *C*, mounted on the testing carriage, and forms, after nearly normal reflection from this mirror, an image of the cross wires at the focus of the observing telescope *D*, also carefully focussed for parallel rays. *D* is furnished with a micrometer eye-piece with double cross wires of the usual construction.*

a is an ordinary condensing lens, serving to concentrate the light from a lamp or gas flame on the cross wires of *A*.

Both telescopes being accurately focussed for parallel rays, and the telescope *D* being set so that its axis is in the prolongation of the straight edge under test and perpendicular to the mirror *c*, the glass plate *B* is adjusted until the illuminated field of *A* is central in the eye-piece of *D*.

The telescope *A* and the micrometer eye-piece are then rotated until the cross wires of each are parallel to the plane of the edge to be tested. The carriage is then placed at one end of the edge and the wires of *D* set so that they are just bisected by the image of the horizontal cross wire of *A*. Then if the edge be perfectly straight it is

---

* For the sake of avoiding confusion in the measurement it is a good plan to cut out the ordinary fixed wires and retain only the double movable ones.

evident that the relative position of the micrometer wires and this image seen by reflection from *c* will remain the same for all positions of the carriage, but that any elevation or depression will at once cause a deflection of the image, the amount of which is accurately measured by the micrometer. The possible delicacy of the method is limited only by the size of the telescopes employed, provided only the mirror *c* be of the same size as the object glasses.

An objective of quite moderate size is, however, sufficient. The dimensions and constants of the apparatus used in the present case were as follows:

Aperture of telescope,	40 mm. (1·6″)
Focal length of telescope,	314 mm. (12·3″)
Constant of micrometer,	1 div. corresponds to $\frac{1}{200}$ mm.

A deflection of the image through a distance of $\frac{1}{200}$ mm. at the focus of the observing telescope, corresponding to one division of the micrometer head, meant therefore an angular deflection of the beam of light of 3·2″, and therefore since the deflection of the beam of light is doubled by reflection, an angular deflection of the carriage and mirror through about $1\frac{1}{2}$ seconds ($1\frac{1}{2}$″).

This constant can be and was measured directly in at least two other ways: (1) By inserting a strip of mica of measured thickness under one end of the carriage, and measuring the deflection produced, and (2) by displacing the cross wires of the first telescope through a known angle by means of the divided circle of the spectroscope table on which it was mounted, and measuring the corresponding deflection. The mean angular value (for the carriage) for one micrometer division, as found by all these methods, was for the apparatus used about 1·5″, corresponding to a displacement of one end of the carriage through about $\frac{7}{150000} = \frac{1}{21000}$ of an inch. One division of the micrometer head corresponded then to about the limit of accuracy imposed. The resolving power of the telescope employed was such that differences of at least one-fourth this amount could be measured with

certainty;* indeed, readings were always made to tenths of a division, two successive readings rarely differing by more than 0·2 div. from one another.

A fairly typical set of readings taken during the process of grinding one of the edges is given in the following table. Here the two readings corresponding to the same position of the carriage were not taken successively, but form two of a continuous set beginning with No. 1, and ending with No. 14, according to the method of testing presently to be described. Added to the error of reading we have then the errors due to accidental particles of grit getting under the carriage between two readings, the error, if any, due to the movement of the carriage in opposite directions, and the error due to systematic changes in any part of the observing apparatus.

TABLE I.

No.	Reading.	No.	Reading.	Mean of Two Readings for Same Position of Carriage.	Differences from Mean.	Mean Error.	Probable Error of Single Setting.
1	14·7	14	15·0	14·85	·15	From 14 observations = ·2 div.	As determined from 14 observations $\epsilon = ·61 \frac{\sqrt{\Sigma\theta^2}}{\sqrt{\pi - 1}}$ = ·16 div.
2	15·3	13	15·0	15·15	·15		
3	15·6	12	15·2	15·40	·20		
4	14·1	11	13·5	13·80	·30		
5	15·0	10	15·0	15·00	·00		
6	13·7	9	14·4	14·15	·35		
7	14·0	8	14·6	14·30	·30		

When the bar was approaching completion considerably greater care was taken in cleaning the surfaces before testing, and the results were then considerably better; for com-

* Resolving power as ordinarily used is defined by the relation $\epsilon = \lambda/\Delta$ where ϵ is the smallest angle which can be "resolved," or the angle as viewed from the objective between two fine lines or points so close together as to be just distinguished apart; λ the wave length of light, and Δ the diameter of the objective. In this case $\epsilon = \frac{·000055}{40·5} = 2·5''$, a quantity considerably greater than it was stated it was possible to distinguish. It must be remembered, however, that it is easier to distinguish differences between two successive positions of a single object than to determine whether two bright objects placed close together are separate or not, because in the one case there are two sets of diffraction fringes which overlap and cause confusion, and in the other case only one set whose position has only to be judged with reference to some fixed object (in this case the cross-wires) so far distant from it that no overlapping and consequent confusion results.

parison a set of readings under these more careful conditions of testing is given in Table II, which shows that we may rely on the correctness of the indicated error to at least 0·1 div., that is to about $\frac{1}{200000}$ inch.

TABLE II.

Edge No. 1, final.

No.	Reading.	No.	Reading.	Mean of Two Readings for Same Position of Carriage.	Difference from Mean.	Mean Error.	Probable Error of Single Setting.
1	37·2	16	37·6	37·40	·20	Mean error of these 16 readings 0·07 div.	Probable error of single setting $= ·67\sqrt{\frac{\epsilon\theta^2}{n-1}}$ $= 0·06$ div.
2	37·5	15	37·6	37·55	·05		
3	37·3	14	37·2	37·25	·05		
4	37·8	13	37·7	37·75	·05		
5	36·8	12	36·7	36·75	·05		
6	37·2	11	37·2	37·20	·00		
7	37·3	10	37·1	37·20	·10		
8	37·0	9	37·1	37·15	·05		

When the finished straight edges arrived, each one was set up with its edge horizontal, being supported in position by two wooden supports, as shown in *Fig. 2*, placed about one-fourth the length of the bar from each end. One of the four-inch straight edges, No. 1 (*Fig. 1 c*), was first tested and was found to fall so far below expectations that we determined to attempt the correction of it ourselves by grinding down the edge with fine emery. Three grinding tools were therefore prepared, of the form shown in *Fig. 2 A*, of different lengths, one being about twelve inches long, another seven inches, and the third about three inches long. For the purpose of approximately determining the amount removed, a fine micrometer screw, with a large divided head, reading to $\frac{1}{1000}$ mm. $= \frac{1}{25000}''$ was mounted so as to be used as a beam caliper, but it was found that after a little practice with a given grade of emery it was possible to judge very closely of the amount removed by the time of grinding and the pressure used. Besides, the process of testing is so rapid that the whole operation of observing, reducing results, and plotting the curve requires on the average less than ten minutes, and it is, therefore, better to determine the complete curve for the edge after each grinding. The routine method of doing this was as follows:

The carriage was placed first with one end coinciding

with the end of the straight edge, and the reading of the micrometer taken; it was then moved forward its own length and another reading taken, and so on to the end. A similar set was then taken going in the reverse direction, and the mean taken of the two readings (going and coming) for the same position of the carriage, as has already been indicated in Tables I and II.

From this set of means the curve was plotted as follows: The difference between each reading and the next successive one, when multiplied by a factor depending on the constant of the micrometer and the length of the carriage, will evidently represent the difference in level between the two ends of the carriage in the second position, as referred to the line of reference, viz.: the direction of propagation of the incident beam of light. If then these differences be successively added and the numbers so obtained plotted as ordinates to a curve whose abscissæ are distances along the straight edge, the resulting curve will be that of the edge in question. For convenience in plotting, the differences are taken not between successive readings beginning with the first (although this was the plan first adopted), but between each reading and the general mean, the object being to make the ends of the bar coincide with the axis of plotting, and at the same time furnish a check on the numerical reduction of the observations. The following set of readings, Table III, will serve as an example of this method of reduction, the readings being those made on the first straight edge tested (No. 1), just as it came from the makers.

TABLE III.

No.	Position on Bar.	Mean "Going" and "Coming."	General Mean.	Difference.	Σ differences $= y$	$y' = \cdot00007 \times y$ Difference of Level (Inches).
0	0	—	190·4 ÷ 7 = 27·2	—	0·00	·00000
1	7 inches	29·5	27·2	+ 2·3	+ 2·3	·00016
2	14 "	30·5	27·2	+ 3·3	+ 5·6	·00039
3	21 "	28·5	27·2	+ 1·3	+ 6·9	·00048
4	28 "	25·3	27·2	− 1·7	+ 5·2	·00036
5	35 "	25·8	27·2	− 1·4	+ 3·8	·00027
6	42 "	25·6	27·2	− 1·6	+ 2·2	·00015
7	49 "	25·0	27·2	− 2·2	+ 0·0	·00000
		190·4				

As seven-inch intervals on the bar are too great for accurately determining its form, an intermediate set of readings was then taken, beginning at a distance from the end equal to one-half the length of the testing carriage. This set, repeated in return as for the first set, was then reduced independently in the same manner and plotted with the first. As the second series of points so obtained is not necessarily referred by the process of reduction to the same axis of abscissæ as the first, it is generally necessary to adjust the second set with reference to the first either by an elevation, depression or rotation of this axis. Usually a simple inspection would show which of these three operations was necessary.

For example, in the case of the bar just cited the readings at the intermediate points were as follows:

TABLE IV.

No.	Distance from End.	Mean of "Going" and "Coming."	Differences.	Σ' Differences $= y$.	$y' = y \times$ '00007.
0	3½″	—	—	000	'00000
1	10½″	29·5	+ 2·4	+ 2·4	'00017
2	17½″	29·5	+ 2·4	+ 4·8	'00034
3	24½″	27·8	+ 0·7	+ 5·5	'00038
4	31½″	25·4	— 1·7	+ 3·8	'00027
5	38½″	26·5	— 0·6	+ 3·2	'00022
6	45½″	25·6	— 1·5	+ 1·7	'00012
7	End	25·2	— 1·9	— ·2	'00001

This series of points is plotted in *Fig. 3*, together with those of Table III.

If the curve were drawn through both sets of points at once as they stand, it would present a series of waves of regular period (as shown by the dotted curve) which there is no reason to suppose exist.

If we simply rotate the second system of points about the point *a*, we find that every point of the second system will fall nearly upon the curve drawn through the first set, the outstanding differences being such as we might readily suppose to exist.

The most probable general form of the edge as determined from these two sets of observations, at three-and-one-half-inch intervals may, therefore, be considered to be

represented by the heavy line, *Fig. 3*. It would, perhaps, be better to use a carriage only as long as the shortest testing interval, were it not for the fact that in the first stages of the correction it is not necessary to take intermediate points, and the process of testing at seven-inch intervals is much more rapid than that at three-and-one-half-inch intervals with the shorter carriage. It would be best for this reason to have two carriages, one, say, of seven, the other of three and one-half inches length, the former to be used in the first stages and the latter in the final stages of the testing. The shorter the carriage, too, the greater the accuracy attainable with a given size of mirror and telescope. Although the shortest interval at which observations were plotted was three and one-half inches, the observations were in a sense continuous from one end of the bar to the other, for the motion of the carriage was so smooth that the motion of the image in the micrometer eye-piece could be observed during the motion of the carriage. If any sudden deflection was observed between two points of observation, that particular part of the edge was always subjected to an examination at much shorter intervals.

The method of grinding, however, was such that the introduction of any irregularities of short period was extremely improbable, and, in fact, except in a few exceptional cases, such sudden changes were never observed.

The general process of grinding down the edge was to select (after each test had been made) a grinding tool corresponding to the character of the irregularity and a grade of emery corresponding to the amount to be removed, and grind away at the high places a length of time depending on the judgment of the operator. The edge was next very carefully cleaned by first washing thoroughly with coal oil or benzine, polishing with a piece of fine crocus cloth to remove any edge burr that might have been raised during the grinding, and finally rubbing the surface with a piece of linen or, better, chamois cloth. The bearing steps of the testing carriage were also carefully cleaned and the carriage placed in position and passed back and forth from one end to the other several times until not the slightest feeling of

grinding or roughness due to any minute remaining particles of emery or dust could be detected.

When properly cleaned and polished the carriage ought to "float" on the edge almost as easily as one well-made surface plate on another. When this cleaning is properly performed the readings "going" and "coming" for the same position of the carriage agree with each other and may, as already stated, be depended on to 0·1 div. of the micrometer head.

The process of working down the edge by this process, successively testing and grinding, is very rapid, provided the material of which the edge is made is uniform and homogeneous, and, what is still more important, free from initial strain due to hammering or rolling. The characteristic successive steps in working down the edge first taken are shown in *Fig. 4, a, b, c*, etc., the final stage being represented in *Fig. 4, d*, an inspection of which will show that the maximum error remaining was less than $\frac{1}{25000}$ inch, an error considerably less than the limit imposed.

This was so encouraging that the remaining edges were corrected in the same manner.

Edge No. 3, the next one taken in hand, is represented in its initial state in *Fig. 5*. As will be seen, it was considerably better than edge No. 1, but that the errors were considerably larger than could be allowed. In the process of working down this edge an unexpected difficulty presented itself—a difficulty due probably to a want of proper annealing of the steel bar of which the straight edge had been made. During the grinding the bar changed its form repeatedly, the changes observed between two successive grindings being far greater than could have been caused by the simple removal of too great an amount of material at local places. Another curious thing was that the local grinding of a high spot seemed in many cases to increase rather than diminish the error at the point of grinding; in other words, the metal seemed to swell up under the action of the grinding tool. Then, after a series of successive attempts to reduce the "hump" with very little success, the material seemed suddenly to give way all at once, and a

deep hollow was the result. The grinding down of the extreme ends was a matter of special difficulty, as the springing there was especially bad. It seemed almost impossible to attain as high a degree of accuracy in this case as in the preceding, and after spending a good deal of time on the bar it was finally left in the state shown in *Fig. 6*, with the intention of making the final corrections after it had been clamped in place, hoping that the clamping might prevent the springing which proved so troublesome.*

The correction of edges Nos. 2 and 4, the opposite edges of the one bar *c*, proved the most difficult task of any. The warping, presumably on account of bad annealing, was specially bad, and working on either edge almost invariably affected the form of the other, so that it was necessary to reach the final result by a series of successive approximations, working first on one edge until it was nearly right, then on the other, then on the first again, and so on until the amount to be taken off from each side was so small that its removal did not affect its neighbor.

It was necessary also to make a specially light bronze testing carriage for this bar, in order to avoid errors due to the deflection of the bar by the weight of the carriage, errors for which it is true allowance might have been made, but which it seemed better to avoid if possible.

The deflection of the bar due to its own weight here becomes of importance.†

It was reduced as far as possible by placing the supports about one-fourth the length of the bar from each end, under which conditions the deflection at the centre is only about one-fortieth that experienced when the bar is supported at

* It must be remembered that the movements observed are, after all, extremely small, the springing rarely amounting to more than ·00005 inch, and usually much less.

† The deflection of a uniform bar supported at its ends is

$$\triangle = \tfrac{5}{384} \frac{s}{E} \frac{l^4}{d^2}$$

where s is the weight of the bar per cubic inch, l the length (in inches) and d the depth. In this case assume $E = 25{,}000{,}000$. $\triangle$ is found to be ·0027 inch, a quantity corresponding to about fifty div. of the micrometer.

the ends. This slight outstanding error was in the first stage of the correction neglected, as it was intended to make the final correction *in situ*, thus eliminating at once all errors due to flexure. The initial curves for edges 2 and 3 are given in *Fig. 7*, the final curves in *Fig. 8*.

This work was mainly for the purpose of obtaining some idea of the capabilities of the method and determining the limit of accuracy which it was practically possible to obtain without too great an expenditure of time and labor.

As regards the first point, a glance at the final curves will show that the extreme error for edge No. 1 was, as has already been stated, less than $\frac{1}{25000}$ of an inch, for edge No. 2 it was less than $\frac{1}{40000}$ of an inch, and for edge No. 4 about the same as for No. 2. In the case of No. 3, the error is considerably greater than this, on account of the special difficulties already mentioned. As regards expenditure of time, these results were reached in eight days (February 16th to February 24th), an average of only two days' work for each edge, which, for the degree of accuracy obtained, cannot be considered extravagant.

It was fortunate that no more time was spent in an attempt to secure a greater degree of accuracy, for the changes which the bars experienced either during the setting up of the instrument or during its transportation across the ocean, were very much greater than had been anticipated. A preliminary test of the straight edges, after their arrival in Paris, showed that they were very badly warped, indeed, one of the edges being out nearly ·0004 of an inch.

Notwithstanding the comparatively large amount of material which it was necessary to remove, it was determined to this time do *all* the grinding while the edges were firmly clamped in their final position, in hopes that this clamping might prevent the springing of the steel bars, which had before proved so troublesome, especially with edges Nos. 2, 3 and 4.*

* The author is now of the opinion that if most of the material had been removed while the bar was free, many of the difficulties encountered in the final stages of the work would have been obviated.

The clamping screws having been screwed firmly down, a second test was taken, and showed that the form of the edges had not been materially changed by the clamping action. The testing carriages used were now the actual carriages to be used in the final work, a mirror being mounted on each one in such a way that any one of the four edges could be tested without moving the optical part of the testing apparatus. An innovation was introduced in the way of grinding tools, which was in many respects a step backward.

Instead of the iron grinding tools already described, a number of rectangular blocks of emery, of different lengths and of varying degrees of fineness, were prepared. To protect one edge from the action of the grinding block while the adjacent edge was being worked upon, one side of the block was covered with paper.

The reduction of the large irregularities was performed by the mechanician of the laboratory, but in the final stages of the work it was found necessary to return to the iron grinding tools previously used.

After the edges had been brought to about the condition shown in *Fig. 5*, we took the grinding in hand ourselves, and in a few days, with the experience already acquired, brought the edges to their final condition, shown in *Figs. 9, 10, 11, 12.*

The difficulties encountered in this work were greater even than had been experienced in the course of the work on the free bars. In the first place, the initial strain in the bars was not allowed to manifest itself freely as before, on account of the clamping action of the screws, which was not, however, great enough to entirely prevent what seemed to be a gradual or often sudden "creeping," which proved very troublesome. Moreover, the work on any one edge was almost certain to affect the trueness of the adjacent edge, so that, in this case, all the edges had to be reduced by the process of approximation, which has already been referred to as necessary in the previous work, in case of edges Nos. 2 and 4, some of the individual steps of which were more satisfactory as regards a single edge than the final result for that edge. It is especially worth noting,

however, that all, or nearly all, of the difficulties encountered were due to the bad material, or rather the bad state of the material, of which the bars were made. Had the steel been uniform in texture, and either thoroughly hardened and seasoned or thoroughly annealed, the time required to complete the work would have been reduced one-half, and probably more. Even in the state of strain, however, there was no difficulty in reducing the errors of the edge to an order of $\frac{1}{50000}$ inch. An hour or two hours' work usually sufficed to bring about this order of accuracy when the initial error was from five to ten times this amount. The time taken to bring all four edges to their final state, as shown in *Figs. 9–12*, was between 40 and 50 hours, an average of from 10 to 12 hours' work on each edge. As will be seen by inspection, the accuracy is rather greater, on the whole, than was attained in the first work, the greatest absolute error for two of the edges, at least, being not greater than $\frac{1}{500000}$ inch, with a mean error of less than $\frac{1}{1000000}$ inch in the whole length of 52 inches. To make a straight edge of this length accurate to this degree, by the ordinary method, would require an expenditure of time which would render it impracticable as a commercial operation. The results of the preceding work, however, show conclusively that, with suitable material, such edges may be prepared from the planed bar at an expense (for labor) not exceeding $3 per foot of length for edges, four feet long, accurate to within $\frac{1}{500000}$ inch for their whole length.

For longer edges the cost would probably be somewhat less, for shorter ones somewhat more per foot of length. *There is no limit to the length which may be made straight to this order of accuracy quite without reference to any material standard*, an important consideration when it becomes a question of making standards six to ten feet in length.

Errors due to flexure are corrected in the process itself, it being only necessary that the edge be tested when supported in the same manner and the same position in which it is to be used. This allows the use of comparatively light bars instead of the deep girder forms necessary when the ordinary

method of correction by working three edges to one another is used, a process which requires that at least two of the bars be stiff enough to avoid a perceptible change of form when turned upside-down, a condition very difficult to secure when the bars become of unusual length.

It is difficult to see what obstacles remain to be overcome in the successful application of this method to commercial work, except the single one of obtaining homogeneous and well-tempered bars of metal upon which to operate. As has been seen, it is possible to produce straight edges of the order of accuracy herein stated rapidly and cheaply, even when the material is not properly prepared, but these edges are not sufficiently permanent under handling to warrant their being brought to such a degree of accuracy unless they are to be permanently clamped in place.*

Given a bar of proper material, it may be confidently stated that straight edges of from five to ten feet in length, or even longer, if desired, may be produced with an error not exceeding $\frac{1}{100000}$ inch in their whole length. The same method may be applied also to the correction of the ways of measuring machines, dividing engines, comparators or any apparatus in which a very accurate rectilinear motion is to be secured. To these last purposes it is especially applicable, as it allows the testing to be made and the corrections to be applied in any desired position of the edges or ways upon which the work is being done, which renders it possible and practicable to always correct the ways when the bed which supports them rests in the position which it is destined finally to occupy, compensating then at once for all the effects of flexure due to want of rigidity, and twist or other distortion due to the manner of support.

To sum up briefly, the principal advantages which the method seems to possess are:

(1) Possibility of producing one edge, and one edge only, of any required length and of any required order of accu-

* There has been no perceptible change in the edges since they were first finished, which, at the date of writing, was over six months ago, during which time the instrument has been in use almost continuously.

racy, without reference to any previously existing edge or material standard.

(2) The possibility of measuring definitely the errors in this edge and mapping them for future reference, so that it will not be necessary to carry the work on any edge further than the desired order of accuracy.

(3) Ability to test and correct an edge in any position, and to readily verify its correctness at any future time, recorrecting it if necessary without removing it from position.

(4) Rapidity and cheapness in securing a desired result.

This last is an important practical advantage which leads me to hope that the article may not be without interest to the intelligent mechanics and instrument-makers of this country, who are always ready to adopt any practical methods which will lead to greater accuracy in the production of certain classes of high-grade work.

A number of modifications of the general method which may prove serviceable in certain cases may be proposed. Those familiar with the optical arrangements will at once see that instead of two telescopes, arranged as shown with the glass *B*, all that is absolutely necessary is a single one, occupying the position of *C*, and provided with a pair of illuminated cross-wires, the image of which will be seen in the field of the eye-piece when the telescope is focussed for parallel rays and the mirror is nearly perpendicular to the axis of the telescope. The deflection of the image from the cross-wire itself might be measured as before, or perhaps even more simply by the aid of a fine scale in the eye-piece. As it is desirable for the sake of accuracy to use a double movable wire to fix the position of the deflected image, and as it is also desirable to be able to move the set of wires whose image is observed without moving those in the micrometer eye-piece, a better arrangement would perhaps be that shown in *Fig. 13*. Here the illuminated cross-wires are placed at the end of a short tube *b*, placed at right angles to the axis of the telescope. At *c*, the intersection of the axis of *b* with the axis of the telescope, is placed either a plane parallel glass at 45° covering the whole field,

or a small right-angled prism covering one-half the field. *D*, as before, is simply a condensing lens which serves to concentrate the light on the cross-wires in *b*. With this device the whole arrangement is rendered very compact and convenient to use, as both sets of wires are close to the observer. Means might easily be provided by which the observer could himself move the carriage along the bar to any desired position without leaving his seat; but as the one who is doing the grinding is always at liberty during the operation of testing, the necessity for such a device is obviated.*

For horizontal edges and ways, a somewhat simpler method may sometimes be used. Instead of measuring the deflections of the testing carriage optically, they are measured by means of a delicate level which is secured to it. Level bubbles can now be obtained so sensitive that one division on their scale corresponds to one second, and as one-half a division is easily read with certainty, it follows that for a carriage of the same length deflections nearly as small as those measured optically may be determined more directly in this manner.

By mounting the level as shown in *Fig. 15*, it would be possible to examine edges inclined at any angle in a vertical plane; but as the method is a gravitational one, it fails for all edges out of this vertical plane.

---

* It is usually best to have two persons in doing the work, one of whom attends to the grinding, the other to the testing. One observer, however, can easily test as rapidly as three or four can grind.

The usual method of optical testing is to place a telescope on the carriage which moves on the straight edge, and direct this telescope either at a very distant object, or better, at the cross-wires of a second collimating telescope placed in line with the straight edge as shown in *Fig. 14*.

We can then observe in either telescope (their axes being now in the same straight line) the movement of the image of the cross-wires of the other as the carriage is moved along.

The primary disadvantage of this method is that it makes the testing carriage much heavier than the mirror does, a very serious objection when great accuracy is demanded. Then, for a given size of telescope it is only one-half as delicate as the mirror method, as the angle through which the image is deflected is, in this case, the same as that of the carriage, instead of double that angle as in the case of the mirror method.

SUPPLEMENT.

Aside from its applications to the mechanical operations already indicated, the optical arrangement described in this paper would be admirably adapted to the experimental investigation of certain problems connected with the theory of elasticity.

Formulæ for the elastic curves of beams and columns under different conditions of loading have been worked out for a great many cases, but, as far as I am aware, no complete experimental verification of any of these formulæ has been made.

Such a verification, aside from its interest on purely theoretical grounds, affords data for the determination of E, the coefficient of elasticity. This coefficient is often obtained by measuring the bending of a bar supported at the ends by a considerable weight supported at the center, the deflection due to the weight being measured by the aid of a micrometer microscope. This method involves the use of quite as much apparatus as the one which is here proposed, and which gives us, in addition to the absolute deflection at the center, knowledge of what is going on at all parts of the length.

INTERNATIONAL BUREAU OF WEIGHTS AND MEASURES,
SÈVRES, October, 1892.

[*Copyrighted by the Author, 1894.*]

ON GAS BURNERS, GAS PRESSURE REGULATORS AND GOVERNOR BURNERS, GAS GLOBES AND GLOBE HOLDERS, AND GAS FIXTURES.

BY WM. PAUL GERHARD, C.E.,
Consulting Engineer for Sanitary Works, New York City.

[*Concluded from Vol. cxxxvii, p. 421.*]

IV.—GAS FIXTURES.

A few remarks regarding the choice of proper *gas fixtures*—not from the artist's or decorator's point of view, but from the gas engineer's standpoint—may prove useful to the gas consumer; for oftentimes ill-contrived, poorly constructed or defective chandeliers or bracket fixtures are the cause of deficient interior illumination.

Manufacturers of gas fixtures, with rare exceptions, do not pay much attention to the essential requirement of correctness in mechanical execution. The designs of fixtures which they offer may be exceedingly pretty, neat and decorative, but fixtures with too much scroll work often turn out to be quite objectionable, where the gas supplied to the house is improperly purified, or where the distributing pipes for gas are pitched toward the chandelier or bracket, or where the drop is taken directly from the bottom of a line, in which cases the fixtures in a short time accumulate much watery vapor or napthaline, which hardens in the tubing and obstructs the passages for gas.

Firms engaged in the manufacture of fixtures often employ artists at a high salary to design novel forms of expensive gas fixtures, but who has ever heard of a firm engaging a competent mechanical expert, thoroughly conversant with the requirements to be observed to obtain the best illumination and the highest degree of light, to make details for the mechanical execution of the work and to advise on the best kind of burners and globes to be used?

Faulty mechanical execution is by no means confined to

the cheap class of fixtures. Even the best and most expensive modern fixtures are susceptible of much improvement in these respects.

One serious fault is the use of too small gas tubing in the fixtures, through which the requisite volume of gas to supply the burners cannot pass. It is quite common to find gas chandeliers with six or eight lights constructed of one-quarter inch tubing. A simple calculation shows that a one-quarter inch pipe, ten feet long, is only capable of supplying 5·7 cubic feet of gas per hour at four-tenths inches of water pressure; hence the tubing would be just large enough to supply one five-foot burner instead of six or eight. It would be quite useless to use on such fixtures any type of improved governor burner.

It is obvious that where pains are taken to pipe a house for gas with all service and distributing pipes of sufficiently large calibre, it is equally desirable to have the passages for gas in the fixtures of ample bore; in other words, the main tube of a chandelier should be of such a diameter as to be able to pass the necessary volume of gas required by the total number of burners on the fixture, all of which may be lighted at one time; and again, the side tube for each light and the bore of the gas key should be of such a diameter as to afford passage for an adequate volume of gas to each burner.

All gas keys of fixtures should be made strong and of full bore; they should be ground with care, so as to be tight-closing, yet easily turned. A serious defect inherent to many fixtures is the leakage at the stop-cock, caused either by defective workmanship or by keys getting worn out or becoming honeycombed or loose. It is, in most cases, a matter of impossibility to apply any pressure test to the gas pipe system of a house while the gas fixtures are connected, as they usually leak at the fixture joints, at all swing joints of brackets, at extension pendants, and at the gas keys, much more than at the pipe joints.

It should, therefore, be made a rule that all large or heavy chandeliers should be tested before they leave the factory, and their tightness should be guaranteed by the makers when the fixtures are sold.

The hanging or putting in position of the gas fixtures should properly belong to the gas-fitter who piped a building for gas. It has, however, become the universal custom to leave this work to the gas fixture dealer or manufacturer, and it is a common experience that the fixture joints leak more or less when the gas is turned on for the first time at the meter.

The mechanic who does this work should use the utmost care to make the joints absolutely tight, and he should furthermore see that the joints do not become partly obstructed by bits of white lead squeezed out at the inside of the joint.

It is customary that the fixture dealer or manufacturer provides the gas fixtures with burners, and from personal observation and experience I can state that gas-fitters and gas fixture men take scarcely any interest whatever in the kind of burners which they put on fixtures, except that in some instances they may select burners the flames of which will not crack the globes. The bulk of the gas-consuming public are indifferent to the matter, and so we find in practice that even the most elaborate and expensive gas fixtures are provided with only the cheapest and most ordinary kind of burners, and often with badly-proportioned glass globes and cumbersome globe holders. The same size of burner tip is used without regard to the amount of light required in various rooms. The burners are carelessly put on and the gas passages are often partly choked with white lead.

It is far better to buy gas fixtures without gas burners and glass globes, and to purchase separately the very best kind of burners, and to insist on the use of globes with wide bottom opening, supported by shadowless wire prong holders.

Although good burners cost considerably more than the common bad ones, the extra price paid is more than compensated for by the yielding of a more satisfactory light, and by the saving in the gas bill. Some of the governor burners mentioned heretofore are the best obtainable burners and deserve unqualified commendation.

Old-fashioned gas fixtures are often quite defective, and

may even become dangerous by reason of having so-called "all-round" keys or taps which are not made with stop pins. It is a frequent experience, particularly in lodging houses and hotels, that gas leaks, or even cases of asphyxia by inhalation of escaping illuminating gas are caused by the incomplete turning of these all-round keys, or by the accidental turning on of the gas after the extinguishment of the light.

Every now and then, in the course of my professional travels, I come across even first-class hotels having gas fixtures in the guests' rooms which are dangerous on this account, and I likewise find such fixtures with gas keys without stop pins in private houses, particularly in out-of-the-way places, in the cellar, in housemaids' closets, or in servants' bedrooms, where their use is attended with considerable risk. I have, years ago, argued that the use of such fixtures should be prohibited by act of Legislature. It is at least to be hoped that when the time arrives, when building departments will look after the gas piping in houses and exercise a supervision over the gas fixtures, similar to the supervision now enforced in sanitary matters and about plumbing fixtures, they will pay some attention to the above-mentioned defects, with which underwriters have long been familiar.

The modern fixtures are always provided with stop pins, but the metal of which they consist is often much too light, and after some use the pins crack off or bend out of shape. The remedy consists obviously in having all check pins attached to gas keys made of good size and extra strong and to have them well fastened.

Gas-escapes frequently occur with water slide chandeliers, when the water which seals the joint evaporates. The leakage of gas can be avoided either by frequent additions of water, or by putting on the water some sweet oil or glycerine, which retards the evaporation. While water joint pendants are quite common in England and on the Continent, they are not much used in our country, where either cork slide pendants or telescopic extension joint chandeliers are preferred, which dispense entirely with the chain and counterbalance weight and the water seal.

Gas fixtures may be divided into fixtures hung on side walls, or bracket lights, fixtures hung from the ceiling, called drop-lights, pendants and chandeliers or gasaliers, and portable gas fixtures.

Bracket light fixtures may be either stiff brackets, or horizontal swing brackets, with one, two or three joints, or brackets with parallel motion, as used for reading lamps, or for ophthalmoscopic purposes.

The drop lights with one or two arms are usually called pendants, whereas those with three or more lights are called chandeliers. Drop lights with single center lights are sometimes termed "lyras" or hall lanterns. The ceiling joint of such fixtures may be a stiff joint, a hinged joint, or a swing joint. Larger and heavier fixtures are hung with universal ball and socket joints. Chandeliers are often provided with extension fixtures, to pull down, and the joint in these is either a cork or telescopic joint. If the whole chandelier can be lowered, the fixture is hung with counterweights and the joint has a water seal (hydraulic gasalier).

Each burner is usually controlled by a separate gas key, except in rare instances, such as the incandescent "Beacon" lights, the sunburners and the multiple high power flame lamps.

I will close this article with a few remarks regarding the gas fixtures to be used in an average dwelling house.

Much of our life is necessarily spent by artificial light, in business, social and educational pursuits. In dwelling houses, in particular, much of the home comfort after darkness sets in will depend upon the arrangement and distribution of the gas lights.

It is a good plan to mark all the lights on the house plans at an early stage of the construction of the building. It is also desirable that all doors be shown on the plans and the direction in which they swing when opened, so as to avoid the frequent mistake of placing gas lights where the door would open against them.

It is well to fix at once, when locating the gas outlets, upon the height of the same. This depends to some extent upon the design of the fixture used. Where fixtures are

intended for gas only, it is usually safe to place the side outlets at a height of five and one-half feet from the finished floor in all rooms, and six and one-half feet in all halls and passages except where the ceilings are very low, in which case there should be at least two feet between a gas flame and the ceiling (three feet would be still safer). Where combination electric and gas fixtures are used, the gas light is always placed uppermost, while the electric glow lamp hangs down or is placed inclined and pointing downwards. In that case the gas outlet requires to be put higher than usual to avoid exposing the glow lamp to breakage.

It is equally important not to place the lights on chandeliers too high, as it is not the purpose to illuminate the ceiling. In those rooms where a large center-table is placed permanently under the chandelier, such as the sitting-room, the library and the dining-room, the chandelier should be hung low so as to get a brilliant light on the table. The usual height of gas light on such chandeliers is six feet four inches from the finished floor.

Regarding the size of the burners to be chosen, it may be stated in general that for average-sized rooms it is much better to have a few large burners lighted than a larger number of smaller burners.

For lights in hallways, staircases, passages, servants' bedrooms, and the servants' department in the basement, plain, durable fixtures, with little ornamentation, should be chosen; but in the principal rooms of a house, the fixtures should be selected with a due regard to the dimensions of the rooms, the style of decoration, the furniture and the purpose of the room.

The following suggestions may serve as a guide in locating the lights:

Beginning in the *cellar*, there should be a light near the foot of the cellar stairs, also one or several lights in the passages, a light in the wine cellar, and one near the furnace or other house-heating apparatus. Where there is a steam boiler there should be a light near the same with a polished metal reflector, so placed as to throw the light on the water glass tube and on the steam gauge. The side brackets should

be plain, stiff brackets, and the burners should be three-foot burners, preferably surrounded with large wire cages.

In the *kitchen* there should be a two-light pendant with three-foot burners over the center-table, the pendant preferably to be hung with a swivel joint, so it can be placed out of the way whenever the table is removed. There should be a swing bracket light at the kitchen range, and in large kitchens another light over the kitchen sink, each of these to have a four- or five-foot burner. If there is a gas range in the kitchen this should have a separate supply pipe, with a three-quarter or one-inch outlet according to the number of gas burners in the gas range.

If there is a separate *servants' sitting room* or *dining hall*, there should be a two-light pendant over the table, with three-foot burners.

In the *laundry* there should be a fixed center light, where the ceiling is high, or a hinged pendant in case of a low ceiling, also one side bracket light at the wash tubs, with a four- or five-foot burner. If the heating of the sadirons is done by gas there should be a separate supply for these. All the lights should be surrounded with well-fastened large wire cages to protect the flame.

In the kitchen *store-room* there should be a single light pendant, the drop light being preferred, because it does not interfere with the shelves.

There should be a bracket light at the *refrigerator*, and one in the *scullery* at the sink.

In the *butler's pantry* a side light over the pantry sink is desirable, in addition to a center light; but as a rule one two-light pendant with three-foot burners is ample. Should there be a gas plate warmer, this should have a separate supply.

Continuing the consideration of the servants' department, there should be one side light, with three-foot burner, and with large wire globe or cage in each *housemaid's closet* or at the housemaid's sink. In the *linen closet* the light should preferably come from a pendant with wire cage.

The *servants' bath-room* should have a side light with three-foot burner, and there should be in each *servants' bedroom*

one light, not placed near the bed or near window curtains. These lights should be supported on stiff brackets, and they should be surrounded with wire cages. Three-foot burners will give ample light, and it is particularly desirable, if the servants' bedrooms are on the top floor of the house, where the gas pressure is highest, to use automatic governor burners.

The *servants' stairs* and *rear halls* should have a sufficient number of single stiff bracket lights, with three-foot burner and wire cage. As a rule, one light on each floor landing will be sufficient. The use of a polished reflector to light up dark passages is much to be recommended.

Turning now our attention to the front portion of the main house, there should be a center drop light, with one four- or five-foot burner in the *outer vestibule*, and this light should be so placed as to light up the house number over the front door. Outside lanterns, though not much used except for large mansions, form a very useful feature and are a great protection against burglaries.

There is generally a center light in the *front hall* near the inner vestibule door, or directly opposite the hat rack; also one or more bracket lights in the main hall passage-way.

A bracket light, sometimes coming through a mirror, is placed on the upper stair landing, and there are stiff bracket side lights with one or two arms, in the center of each *stair-case hall*. Lights on the stair newels are not used as much as in former days.

In the *drawing-room*, *reception-room* or *parlor*, a better, more uniform, and more equally diffused illumination can be obtained by discarding the cumbersome center chandelier, with its cluster of lights all concentrated in one place, and placing instead side lights around the walls. In rooms exceeding eighteen feet in width, however, both side lights and chandeliers should be used. Bracket lights may also be placed at the sides of the fireplace, or upright lamps on the mantelpiece.

The drawing-room, above all rooms in a house, requires a brilliant illumination in order to light up effectively the

faces, the dresses and the jewelry of the company, and therefore large, five- or six-foot burners should be used. It should also be borne in mind that the color of the walls and ceiling, of the draperies and furniture, has considerable bearing upon the question of lighting up such rooms properly. Light colors reflect the light, and are, therefore, better than dark colors, which absorb light. Dark-colored rooms require more lights and larger burners to be effectively lighted.

A flood of warm and soft light may be obtained by using sun burners in the ceiling, and this is much to be preferred to the direct glare from ordinary chandeliers. Owing to the difficulty of placing gas lights close up to the ceiling, it must be admitted that for ceiling illumination of drawing-rooms the electric light offers a more promising field to the artist. The electric glow lamp is also much to be preferred from a decorative point of view for lighting up cosy corners, recesses in bay windows, etc.

Regarding the lighting of *dining-rooms*, however individual tastes may differ, the chief problem is, without question, to light up the dining table brightly and artistically, yet not too brilliantly. A center chandelier, with four, six or eight arms, and five-foot burners, should be the chief feature, to which is sometimes added an extension or slide pendant with Argand burner. There should be side lights at or on the sideboard, and sometimes side lights at the mantelpiece. Where there are fine paintings on the wall, side lights should be suitably arranged so as to display these to best advantage. A side light at the carving table may also prove a great convenience.

As the dinner table is the chief feature of the dining-rooms, so are the reading table and the writing desk the chief features of the *library* and the *sitting-room*. Where there is a fixed center-table a chandelier with extension lamp may be used, together with side lights at the reading table or reading chair. The light in this room should not be too brilliant, except at the writing desk or the reading table, where an Argand table lamp, or a bracket Argand burner of good candle-power should be fitted up so as to concentrate the light.

In all these rooms grate fires or gas logs may be fitted in the fireplaces and require separate and independent supply lines from those gas pipes which supply the fixtures for lighting.

The *billiard-room* requires a drop in center of the billiard table, with from four to six large burners; also a side light at the lavatory.

The *boudoir* of the lady of the house, and the *den* of the master of the house may be treated differently in each case according to the taste of the occupant, and side illumination will generally be used, together with a strong and powerful light at the reading desk or writing table.

The *sewing-room* should have a strong side bracket light at the sewing machine, with a five-foot burner.

Bedrooms, as a rule, should not have ceiling lights. There should be a bracket light at the wall against which the bed stands, near the bedstead, and another light near the washstand. The toilet table or bureau generally has two side lights, one on each side of the looking glass, to which, for ladies' dressing tables, a mirror light, suspended high or dropped from the ceiling in center and in front of the bureau, is added. Near the fireplace there may be a bracket light for a reading lamp, and if there are gas logs there should be for these a separate supply.

According to its size and the number of fixtures, the *bath-room* may have one or two stiff side lights with four- or five-foot burners, generally one light at the wash basin and another at the water closet. There should be a separate gas supply for a gas heating stove or a gas fireplace heater, or for gas jets in local ventilating flues. The *nursery* may be lighted similar to the bedroom.

The hints thrown out in the foregoing paragraphs may be used as a general guide in locating the gas outlets of a house. As regards the large rooms, no hard and fast rules can be given, as so much depends upon the individual taste of the decorative artist, and upon the decorative features of the house.

ENGINEERING PRACTICE AND EDUCATION.

By Gaetano Lanza, S. B., C. & M. E.,
Professor of Theoretical and Applied Mechanics, Massachusetts Institute of Technology.

[*Continued from Vol. cxxxvii, p. 468.*]

Steam.—Such works as those already referred to have, in many cases, been carried out by the Government at public expense, and hence they have often been classed as public works, although some of them, especially railroads, are, in this country, private enterprises. It is in connection with such works as these that the common idea of engineering has been exclusively or, at least, chiefly associated. In former times works of great magnitude were almost always undertaken by the Government, because it alone could command the needful capital to execute them; or if in any case private capital was invested, it was subsidized by the Government. Works for the Government at the present day are often let out in whole or in part to private parties to execute. Moreover, this is preëminently an industrial age, and we have consequently so much engineering involved in the operations of private concerns that the total amount done for them far exceeds that done for the Government. Hence we shall, later on, consider what may be termed private enterprises. With the exception of mining and a few others, we might include most all such enterprises as involve engineering to a considerable extent under the term manufacturing.

Before entering upon a consideration of what are the engineering problems involved in these industries, I must first refer briefly to the development of the use of steam and the steam engine. To-day one can hardly undertake any engineering work, even of small magnitude, without the use of steam, and no engineering work of any considerable magnitude can be carried on without a considerable

use of steam. We have become so accustomed to this state of things that it is very hard to realize the condition of the industrial world before the general introduction of this agent, when the only available sources of power were water-power, wind-power and the muscular power of animals and men; and when we contemplate any large work of those days we are led, in expressing our admiration, to couple our words of praise with the remark, "notwithstanding their lack of facilities for performing such work." I shall not stop to consider the earliest history of the introduction of steam for power, involving the work of Hero, of Savery, of Newcomen and of others, but I cannot avoid making some mention of James Watt, for, if we enumerate the important problems that have arisen affecting the development of the steam engine from the beginning down to our own day, we shall find that almost all of them were recognized and taken into consideration in some form by Watt; and, although the improvements that have since been made are enormous, and although the economy of steam that can be realized to-day is far greater than that obtained by Watt, nevertheless the contrast between the modern engines and those of Watt, enormous as it is, is not as great as that between Watt's engines and those of his predecessors, and, moreover, one great reason for the success of James Watt lay in the thoroughly scientific manner in which he did his work. Instead of attempting to evolve out of his own mind, without investigation, a successful engine, he began by making a long and careful series of experiments by means of such an engine as was then available, and by means of other apparatus which he made for his special purposes, and, by studying the faults, the shortcomings, and the chances for improvement in the then existing state of steam engine practice, he succeeded in working out the means of remedying to a very considerable extent the difficulties encountered. He made a series of experiments to determine the actual amount of coal and water consumption per horse-power per hour in the Newcomen engines, such as were then in use in the mines for pumping water. He found the amount of coal and water consumed to be very excessive, so considerable

indeed that the cost of using such an engine was often prohibitive.

He began experimenting with the model of a Newcomen engine to which he had access, and found that the boiler was too small to furnish the requisite steam for the engine. He made a new and larger boiler, and then proceeded so to arrange the apparatus that he could determine, by actual weighing, the amount of water evaporated, and the amount of steam used by the engine in any given time.

In the Newcomen engine, steam was admitted under the piston, and thus the piston was raised; then, for the purpose of allowing the piston to descend, the steam was caused to condense, either by cooling the cylinder by water poured on the outside, or else by a jet of water introduced into the cylinder. In either case the loss was very considerable, and before he completed his experiments he came to the conclusion that in the Newcomen engine at least three-fourths of the steam was wasted, and he set about trying to get rid of this loss.

He gives, as the results of his researches:

(1) The capacities for heat, of iron, copper, and of some sorts of wood, as compared with water.

(2) The volume of steam as compared with that of water.

(3) The quantity of water evaporated in a certain boiler by one pound of coal.

(4) The elasticities of steam, at various temperatures greater than that of boiling water, and an approximation to the law which it follows at other temperatures.

(5) How much water in the form of steam was required at every stroke by a small Newcomen engine, with a wooden cylinder 6 inches in diameter and 12 inches stroke.

(6) The quantity of cold water required in every stroke to condense the steam in that cylinder, so as to give it a working power of about seven pounds on the square inch. These researches showed him what were the difficulties, and cleared the way for his improvements. His first means of saving steam was by the use of an independent condenser, and an air pump, instead of condensing the steam

in the cylinder itself. The following description of his inventions up to 1769 is given in his patent:

"My method of lessening the consumption of steam, and consequently fuel in fire engines, consists in the following principles:

"(1) That the vessel in which the powers of steam are to be employed to work the engine, which is called 'the cylinder' in common fire engines, and which I call 'the steam vessel,' must, during the whole time that the engine is at work, be kept as hot as the steam which enters it—first, by inclosing it in a case of wood, or any other materials that transmit heat slowly; secondly, by surrounding it with steam or other heated bodies; and thirdly, by suffering neither water nor other substances colder than the steam to enter or touch it during that time.

"(2) In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam vessel or cylinder, though occasionally communicating with them. (These vessels I call condensers, and while the engines are working, these condensers ought at least to be kept as cold as the air in the neighborhood of the engines, by application of water or other cold bodies.)

"(3) Whatever air or other elastic vapor is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam vessels, or condensers, by means of pumps wrought by the engines themselves, or otherwise.

"(4) I intend, in many cases, to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner as the pressure of the atmosphere is now employed in common fire engines. In cases where cold water cannot be had in plenty, the engines may be wrought by this force of steam only, by discharging the steam into the open air after it has done its office.

"Lastly, instead of using water to render the piston or other parts of the engine air- or steam-tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver and other metals in their fluid state."

Later, Watt patented the expansion of steam and six methods of using it; the double-acting engine; the double or coupled steam engine; the use of a rack on the piston rod, working in a sector on the end of the beam to secure a truly rectangular motion; a rotary engine. He next decided to add a fly-wheel to his engines to equalize the effect at different parts of the stroke. He then devised his parallel motion; also the arrangement of cross-head and guides now universally used. He also patented the poppet-valve; also a revolution counter; the pendulum governor and mercury steam-gauge; the water glass and the steam engine indicator.

The above gives a partial list of the devices and improvements introduced by Watt into the steam engine; and, whereas we should to-day much prefer to have a modern engine rather than an engine of that day, nevertheless, it is plain that the rate of development is not at all as great as that which represents the change from the engine of Newcomen to that of Watt. That the introduction of the Watt engine to pump water from mines, and to run mills and shops, made a complete revolution in the ways of carrying on industrial pursuits is evident, and equally so that to the work of Watt is due the development of the steamboat and of the locomotive. Indeed, it was one of Boulton & Watt's engines that Fulton placed in the *Clermont*, to drive it when he made his memorable first voyage up the Hudson, in 1807.

Whether, therefore, we consider railroads, or navigation, or mining, or manufacturing of any kind, or applications of electricity, we find that the steam engine has revolutionized the industry, and that no one to-day can undertake engineering work of any magnitude without having to make use of steam.

Now, without stopping to consider further what was the work of the early days—of Watt, of Fulton, of Stephenson, and of the host of other men who had a part in introducing and developing the steam engine—let us consider what have been the later developments that have been made in its use.

And here we may say that the entire impetus towards an

investigation of the defects of the steam engine and the remedies therefor, has been the desire to save coal, and hence to cause the engine to do its work, and to make the boiler produce the necessary steam, with a smaller coal consumption. Economy of coal became at once an item of the greatest importance in the case of the marine engine, for every ton of coal less not only saved the expense of the coal, but also space in the vessel for carrying cargo, which was profitable freight. Indeed, in the early days of the marine engine, one of the questions raised touching its practicability was whether it was possible to carry enough coal for a long voyage. Hence it is that we find on the whole that improvements and economy were more sought after in the case of the marine than in the case of either the stationary or the locomotive engine.

Another fact that has aided in making the improvement of the marine engine more rapid than that of either of the others, is that the work done by it is more nearly constant; and, besides this, when the boat is on a long voyage the engine runs night and day, so that the fires are not put out each day, and rekindled as often.

Next to the marine engine, in this regard, stands the stationary engine, and especially the large pumping engine; although, in the case of the small pumping engine, economy of steam and hence of coal is usually sacrificed to cheapness of first cost and ease of repairs.

Why more attention has been paid, until lately, to economy of steam in the case of the large pumping engine than in the case of other stationary engines may seem strange. but the reason is probably to be found in the fact that such engines are necessarily owned either by the Government or by some rich corporation, whereas it has only been with the enormous development of manufactures that belongs preëminently to more modern times that large engines have been required to any great extent in manufactories, and even to-day we often find in use, in a large manufactory, a number of small engines in many cases in which the substitution of one large one would make a decided saving of coal.

In the earlier engines the valves were set to cut off at some definite point, and the steam supply was automatically adapted to the load on the engine by means of a throttle governor, which varied the pressure of the steam when it came into the cylinder. The first attempt to do away with the losses consequent upon the throttling of the steam was made by George H. Corliss, of Providence, who caused his governor to regulate the point at which the steam should be cut off, and, therefore, he left its pressure as it came into the cylinder undisturbed.

Though this is not one of the earliest improvements, it is, nevertheless, one that has been very far-reaching in its effects, and it is rare to-day that we find any large engines that throttle their steam, as large engines are almost invariably provided with an automatic cut-off.

Indeed, the influence that Corliss exercised on stationary engine practice was very great, and, throughout Europe and America, we find that the Corliss type of engine is very extensively used. But while much may be said in favor of the rotary valves and the drop cut-off, which are so characteristic of the Corliss style of engine, Mr. Corliss, nevertheless, was not identified to any extent with the modern compound and triple engines.

The saving that could be obtained by using steam expansively, instead of allowing it to follow the piston throughout the stroke, was recognized by Watt, and this feature is to be found among the early engines, and so deeply were engineers impressed with it, that they began to build engines to run with shorter and shorter cut-offs, expecting to save steam thereby; but, later, attention was called by a number of engineers and others to the fact that cylinder condensation was an important item to consider, and that with very short cut-offs the effect of cylinder condensation was to bring about a waste of steam; so that, for every different engine running under definite conditions as to steam pressure, back pressure, etc., there is a certain cut-off which produces a greater economy of steam than either a longer or a shorter one.

To explain to any one not familiar with these matters

what is meant by cylinder condensation, I will say that the steam, when it enters the cylinder, is very hot; thus, steam of 100 pounds (*i. e.*, 114·7 absolute) pressure, has a temperature of 337°·7, and, when it leaves, it has a low temperature; thus, if it escapes into the air, its temperature is 212°, or if it escapes into a condenser it is even less.

Now, during a given stroke, the steam on one side of the piston has been escaping into the air or into a condenser, and the metallic walls of the cylinder have been exposed throughout this stroke to this low temperature, hence they must have cooled off considerably and be very much colder than the steam which enters immediately afterwards, at the beginning of the return stroke.

When the steam enters at a high temperature and comes in contact with the cold metallic walls, its first function is to condense and heat these walls, and hence a large amount of steam is condensed in heating up the walls of the cylinder instead of performing work. Now, this cylinder condensation, as it is called, is greater, the greater the difference between the temperature of the steam when it escapes into the air or into the condenser, and that of the incoming steam, and anything that can be done to decrease that difference will decrease the loss due to cylinder condensation. If the cut-off is made shorter and shorter, the gain due to using steam expansively is soon offset by the greater loss due to cylinder condensation.

It is the consideration of the losses due to cylinder condensation that has, perhaps, more than almost anything else, brought about the more recent improvements in the steam engine, both marine and stationary, and now it is also beginning to have its effect in the case of the locomotive. There are several who claim to be entitled to the credit of first pointing out the fact that cylinder condensation exists, and it is not long since a number of articles appeared in the scientific papers claiming the credit respectively for Isherwood, for D. K. Clark, and for Hirn. It is not of any special interest to us to settle this question.

As to the fact that cylinder condensation exists, James Watt found that the chief source of loss in the Newcomen

engine was cylinder condensation, and that was the first thing he undertook to remedy, thereby saving as much as three-fourths of the steam used by Newcomen's engine.

The thing of real importance for us, is to have a number of well-arranged and careful scientific experimental investigations to determine its amount under a variety of different conditions, so fully as to give us reliable information as to how to reduce it to a minimum.

Now, neither of the men mentioned above has made any such complete series of experiments, nor has any other one man done it, but it is a matter in regard to which, through the exertions of a great many, we are making decided progress, and the chief set-back is due to the attempts and claims of those who, ignoring the good example of Watt, make experiments in an unscientific or careless way, and put forward as true, conclusions that are not, and which, if accepted as facts, lead to costly experiments and certain failures. Nevertheless, a good deal of progress has been made, and the world is very much alive to this question to-day. The result has been the adoption long ago of the compound marine engine, and of late of the triple expansion marine engine, so that we find on almost any large steamer either a compound or a triple engine.

In stationary engine practice, the compound engine has frequently been used for water-works engines, but it is only in later years that it and the triple expansion engine have been introduced to any great extent into mills and manufacturing establishments in the United States; and it is only very recently that the compound principle is being introduced into locomotives. A compound engine is one in which the steam performs only a portion of its expansion in one cylinder, and then it enters another and a larger cylinder at a lower pressure, and completes its expansion therein. The result is that the difference of temperature in each cylinder between the entering and the departing steam is less than it is when the expansion is completed in a single cylinder, and therefore the cylinder condensation is less. In the case of a triple expansion engine the expansion is only completed in three cylinders, the

steam doing work in the first, then entering the second at a lower pressure and expanding therein, then entering the third at a still lower pressure, in which last the expansion is completed.

The one reason for expanding in more than one cylinder is to diminish cylinder condensation, while taking advantage of the expansive force of the steam.

Now, in regard to the progress being made in the matter of economy in engine construction, some of the questions that naturally arise are, in any given case:

(1) What degree of expansion should be used?

(2) Is it best to use, under the conditions in hand, a non-condensing, a condensing, a compound, a triple expansion, or a quadruple expansion engine?

(3) If a multiple expansion engine is decided upon, what should be the proportions between the different cylinders?

(4) Should receivers be used, and of what capacity?

(5) To what extent and in what way should steam jacketing be carried out?

(6) What effect, if any, has the piston speed, or the rotative speed on the economy of steam?

(7) Is it better in any given case to adopt a jet, or a surface condenser?

(8) What kind of boilers should be used, and what should be their proportions?

All the above are questions which concern the economy of coal and water; but there are of course many other questions to be answered and conditions to be considered; such as—

(9) What degree of regularity is it necessary to maintain, and how shall we build the governor and the fly-wheel to attain it?

(10) All parts bearing loads must be made of the requisite strength, and the stresses should be carefully calculated so as to secure safety.

As an instance of carelessness in this regard, I need only call attention to the fact that every now and then we hear of some fly-wheel that has burst, has killed a number of people, and destroyed a great deal of property, and I will

say that I have found a number of wheels where it is evident that the stresses were not properly calculated by the designers, and where there is a very small factor of safety, and consequently a large element of risk, and I do not doubt that a proper care in the design would avert a number of the accidents that occur.

Another instance where the better class of builders do take at least a fair amount of precaution as a rule, but where, in many cases, great risks have been taken, is in the case of steam boilers, though the accidents due to steam boiler explosions are attended with so much danger that more effort has been made to exercise a proper supervision in their construction. Indeed, the steam boiler insurance companies exercise a considerable check on the existence of dangerous boilers.

Reverting to the questions concerning the economy of coal and water, a great deal more is known to-day than formerly, and the increase of knowledge on the subject has operated in causing material improvements in engines, particularly for large plants; nevertheless, the complete answers are to be determined in the light of careful and scientific experiments, and these questions now are no longer to be decided by rule of thumb, nor by haphazard trial. They are no longer questions for the inventor to solve, but require the best efforts of the engineer. The really scientific work on this subject is of very recent date, but those who take the responsibility for the expenditure of large amounts of money for steam plants are ever on the alert to get the benefit of any such experiments.

In considering the second question, for instance, the decision must depend upon what other use, if any, is to be made of steam.

Thus, if a very large amount of steam of a very low pressure is required, it may be that it will be more economical to use a simple non-condensing engine in certain cases, rather than a compound, and then to utilize the exhaust steam for the other purposes, as, for instance, for heating; for the exhaust steam is practically as efficient for heating as live steam, and hence, in cases where all the exhaust

steam is used for heating, if we estimate the expense of our power, in coal, at five per cent. of what it would cost if the exhaust steam were not used, we shall have made a large estimate.

Some attempts are now being made to use stationary compound engines with not very high initial pressures, exhausting into the air, or against a small back pressure, and considerable economy is claimed for them. They are now in the experimental stage, however, and it is too early to give a very positive decision in any cases that have thus far been developed. Nevertheless, in locomotive practice, the case is precisely one where the exhaust from the low-pressure cylinder takes place into the air, but in this case the initial pressures are very high, and while the experiments that have been made have not been as full nor as accurate as could be wished, enough has been done to show that a decided saving of coal can be obtained in many cases by the use of the compound locomotive when properly designed and operated.

Another matter that requires the careful consideration of the engineer is how to transmit the power from the engine to the different places where it is to be used, and to see that all this is properly designed. This, in some cases, is accomplished by gearing, in some cases by belting, and in many cases by ropes running in grooved pulleys.

Now that electricity is coming to play such an important part in all our engineering operations, I do not doubt that there will soon be cases where the engine will be employed in driving one or more dynamos, using up a part or the whole of its power, and then the power will be transmitted to the different points where it is needed, as the different floors, or the different shops, or to the different groups of machines, and sometimes perhaps to the different machines themselves by a wire from the dynamo, connected at the other end with an electric motor.

There is no doubt that a large engine can be run with much greater economy of coal than several smaller ones delivering in all the same amount of power; hence it is desirable, whenever there are not other reasons which offset it, to concen-

trate the power plant in one place, and in cases where this is not possible, to do as much as can be done towards concentration. In many cases it cannot be carried out, and in others it can only be done partially; nevertheless, if the power is transmitted by electricity this will be an aid towards such constructions.

Next comes the question of boilers. The contrast between the boilers used at or about the time of Watt and those used to-day is very marked. The pressures in use were very low, and boilers could be made of most any material and of most any shape. Copper was a favorite material, and Watt, in some of his experiments, even tried wood. Later on, cast iron came into use, and later still, wrought iron and now steel has almost displaced wrought iron in boiler construction. Of course, cast iron is still used in many sectional boilers, and in some of the complicated fittings of cylindrical boilers. The early boilers were made without any special pains being taken to calculate their strength, and the pressures were increased by those who used them with so much carelessness that there were a great many accidents.

As pressures rose, however, it became more necessary to look after the matter of strength carefully, and this fact began to have its influence in the shapes and designs of boilers. But even when pressures had reached thirty or forty pounds per square inch, there were still in use a great many marine boilers having a number of flat surfaces which, of course, had to be stayed, but now the pressures have increased to as much as 150 and even 200 pounds, and it has been necessary to adopt the cylindrical form for the marine boiler, so that the marine boiler has changed enormously since early days.

Of the different types of stationary boilers there is no end, but all of them are very different from the boilers of early days. Moreover, pains are taken to day to avoid loss of heat; thus economizers are frequently introduced, by which the feed-water is heated by a portion of the waste heat which would otherwise be lost by going up the stack; pains are taken to lag the boiler if it is internally fired,

or to make some provision in any case to prevent the escape of heat; the pipes are covered, and precautions are taken to save heat in every possible way. Also, the feed-water is very commonly heated by exhaust steam, or otherwise. Then, in establishing a power plant the chimney demands consideration. It must be adequate for the boilers, and it must be properly constructed.

Provision must be made for receiving and storing coal, and this should be arranged so as to save labor, as far as possible, and to deliver the coal as near the boiler as is feasible.

Another use of steam which presents itself is the heating of buildings, and this has to be done in many places where no power is needed and no engine is run, except a pump to feed the boiler, and perhaps an elevator may be run by power derived from a small engine or pump. In this case there used to be but one way of effecting the heating, viz.: to place radiators in the rooms to be heated, and to convey steam to these radiators by pipes. Now, however, ventila tion is considered an important factor, and systems of heat ing are adopted which provide for ventilation at the same time.

I will explain one of these systems as exemplified by what is done in the Engineering building of the Institute of Technology. Steam is used in the building for heating and for power; it enters through the main pipe and passes through a separator before continuing on to the engine; water and wet steam are drawn from the bottom of the separator and put into the heating system, and so is also the exhaust steam from the engine, when the latter is not condensed in the condenser. Besides this, live steam is used whenever there is not enough of the other. The steam passes into the various coils, which will be described. There is, in front of an opening in the wall, the main coil, and in front of that a fan run by a special small engine. This fan draws air in through the coil, *i. e.*, around the pipes forming the coil, and thus the air becomes heated. Then the air is driven by the fan into a duct, which extends all around the sides of the basement into which it is delivered in a slightly

compressed state. This duct is connected with a number of upright channels leading to the various rooms of the building, all of them being lined with tin. At the base of each of these vertical ducts is an auxiliary radiator, to which steam is admitted, so as to add more heat to the air, in addition to that which it received from the main coil. Then there are registers in the uprights which open into the different rooms, also other registers which connect the rooms with outlet flues. Thus, the rooms are heated by the warm air introduced into them. Moreover, there are a number of direct radiators in addition, to provide for more heat in very cold weather. There is also an arrangement for automatically regulating the temperature, so arranged that when it rises or falls a certain amount, 1° above or below the normal, an electrical connection is established, which causes compressed air in a small pipe to close or open the steam valves of the direct radiators or the registers in the case of the indirect system.

There are many other methods of using steam for heating, to which there is not time to refer. Neither is there time to dwell further upon the almost countless uses for steam in connection with the industries and with the civilization of the world.

[*To be continued.*]

THE HEATING AND VENTILATION OF LARGE BUILDINGS.

BY ALFRED R. WOLFF, M.E.*

The lecturer was introduced by the Secretary of the Institute, and spoke as follows:

MEMBERS OF THE INSTITUTE, LADIES AND GENTLEMEN:

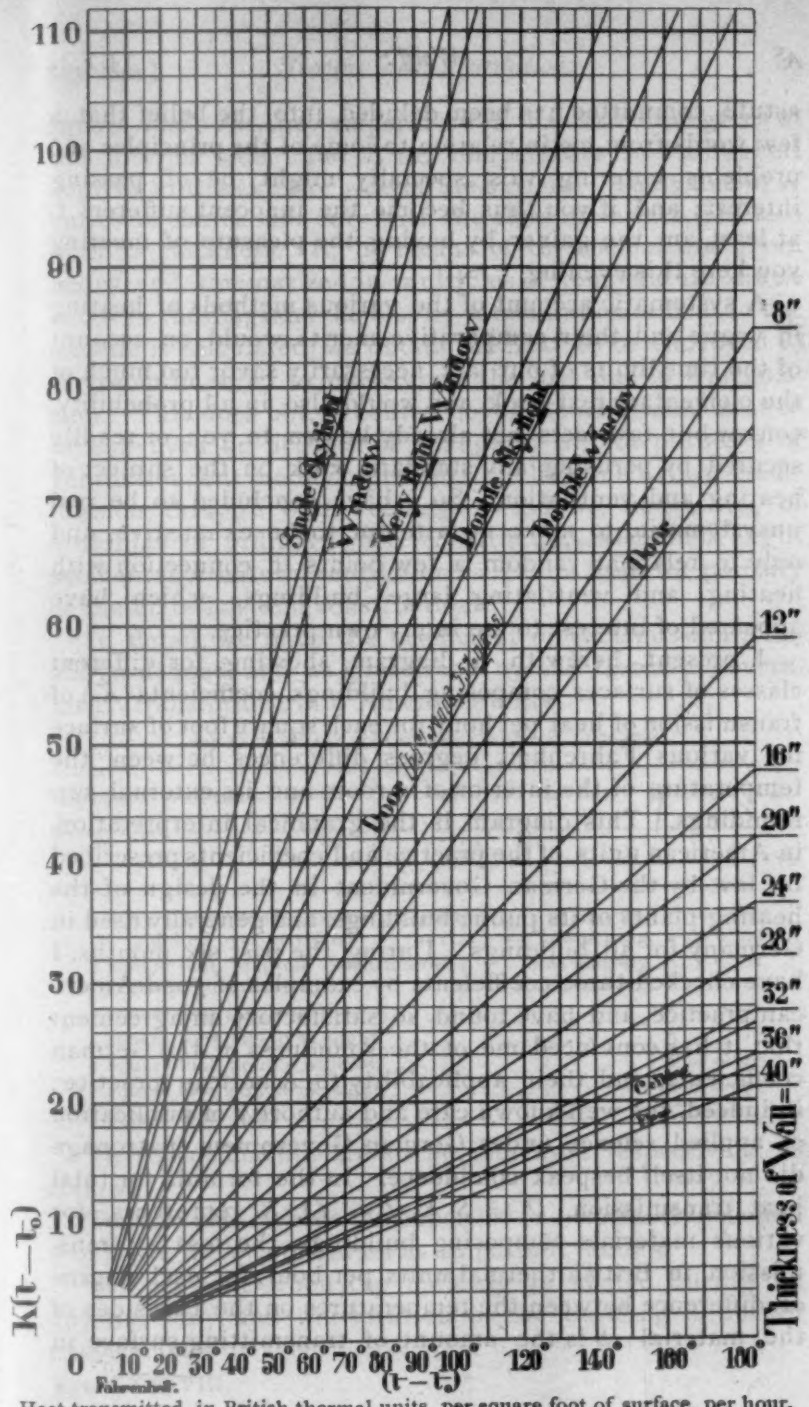
The large building of the present day, at least in America, must meet the needs and comforts of an intense, concentrated, nervous and busy "indoor" community—the pro-

* A Lecture delivered before the Franklin Institute.

duct of our "rush" civilization. The very fact that both business and pleasures are indulged in on a large scale, in ceaseless haste and at high pitch, renders the community participating in them all the more sensitive to external discomforts, and unwilling to put up with any not of their own individual creation. The very "crowding," and the physical strain and nervous excitement incident thereto, render it important in the battle of existence called "life," that the best conditions of health be artificially secured, so as to counteract, if possible, the individual natural neglect. But aside from this, and from a loftier point of view, the modern tendency is to demand the best attainable in every department of work. Whatever the reasons, the demand exists that the best conditions of health and comfort be secured in the large buildings, the meeting places of the multitude. Thus there must be equable temperature, pure air, excellent light and fine sanitation. obtained artificially, almost irrespective of the control, crowding, physical and nervous state of the inmates of the building, and irrespective of climatic and other conditions external to the building.

It is the solution of this problem which converts no small portion of the large modern building into a great factory for the generation and distribution of light, heat, cold, and currents of air and water. It is no longer unusual for our large hotels, office buildings and auditoriums, to contain a boiler plant of 1,000 horse-power, with a corresponding electric lighting, heating, cooling and refrigerating system, nor for the equipment of these plants to require an outlay of hundreds of thousands of dollars. And with these large machinery interests at stake, it becomes important that the skill of the trained engineer be called into play to ensure, in co-operation with the architect, the most desirable and best attainable results, with a judicious expenditure of money.

During the past few years it has been my good fortune to have acted as consulting engineer in the design and erection of the engineering equipment of a number of large buildings, and, more particularly, of the heating and ventilating plants. On this account, doubtless, your otherwise



Heat transmitted, in British thermal units, per square foot of surface, per hour.

astute committee has been deluded into the belief that a few words from me in relation to some of the principles and problems entering this specialty might be of passing interest; and if you thus become the innocent sufferers I, at least, am the gainer by having the pleasure of meeting you here this evening.

A systematic account of the various methods of heating in vogue and their comparative merits, would, on account of the time-limits of our talk, necessarily savor too much of the elementary text-book, and would also, in all probability, convey but few facts not already known to you, or readily secured by perusing any standard work on the subject of heating and ventilation. So I have concluded to be real unsystematic, to make no attempt to be exhaustive, and only to relate at random a few points in connection with heating and ventilating large buildings, which have appeared of interest to me in my own practice.

I present, herewith, a diagram, showing, for different classes of surfaces composing buildings, coefficients (K) of transmission of heat per hour for each square foot of surface for various Fahrenheit degrees differences between the temperature of the interior of a room and its external surroundings. This diagram is the graphical interpretation, in American units, of the practice and coefficients prescribed by law by the German Government in the design of the heating plants of its public buildings, and generally used in Germany for all buildings. During the past six months, I have checked these coefficients by examples of good American practice, and have found so satisfactory an agreement that it has convinced me of the soundness of the German coefficients, and their applicability to American practice; if, indeed, the well-known care and authority of publication of applied science under German Government patronage did not itself bespeak confidence. In the formula for total heat transmission, $Q = S\ K\ (t - t_0)$, K represents, for various materials composing buildings, the loss by transmission, in British thermal units per hour, for each degree of difference between the temperatures on the two sides of the material; S is the amount of transmitting surface in

square feet; t is the temperature in Fahrenheit degrees at the interior side; and t_0 the temperature in Fahrenheit degrees at the exterior side of the surface. The value of K varies, of course, not only with the class of surface, but also with its thickness. If, by means of the coefficients given below, and summarized in multiples of temperature differences in the diagram, the loss by transmission of heat to the outside is calculated, we obtain the heat to be conveyed to the room in order to make good the loss due to transmission. This does not, of course, cover the additional heat to be conveyed on account of change of air for purposes of ventilation, but merely represents the loss due to heat transmission through walls, ceilings, windows, floors, etc., of buildings of ordinary good construction, with such slight accidental or natural ventilation as results from the porosity of the materials and construction.

In detail, we have the coefficient of transmission K as above defined, and as prescribed by the German government (transformed into American units):

FOR EACH SQUARE FOOT OF BRICK WALL OF THICKNESS:

Thickness of brick wall =	4″	8″	12″	16″	20″	24″	28″	32″	36″	40″
K =	0·68	0·46	0·32	0·26	0·23	0·20	0·174	0·15	0·129	0·115

1 square foot, wooden beam construction, planked over or ceiled: as flooring, $K = 0{\cdot}083$; as ceiling, $K = 0{\cdot}104$

1 square foot, fireproof construction, floored over: as flooring, $K = 0{\cdot}124$; as ceiling, $K = 0{\cdot}145$

1 square foot, single window, ... $K = 0{\cdot}776$

1 square foot, single skylight, ... $K = 1{\cdot}118$

1 square foot, double window, ... $K = 0{\cdot}518$

1 square foot, double skylight, ... $K = 0{\cdot}621$

1 square foot, door, ... $K = 0{\cdot}414$

These coefficients are to be increased respectively, as follows:

Ten per cent. where the exposure is a northerly one and winds are to be counted on as important factors.

Ten per cent. when the building is heated during the daytime only, and the location of the building is not an exposed one.

Thirty per cent. when the building is heated during the daytime only, and the location of the building is exposed.

Fifty per cent. when the building is heated during the winter months intermittently, with long intervals (say days or weeks) of non-heating.

The philosophy of these increases is, of course, apparent; for the coefficients, as given, are for heat transmission alone, in usual every-day practice, where the temperature differences in the transmitting portions have assumed a fixed relation with a corresponding fixed rate of flow of heat. But if the building gets chilled or entirely cold, through days or nights of disuse of heating system, the exposed heat-transmitting portions must be first warmed to the staple degree referred to, which demands for the time being additional heat beyond the ordinary rate of supply, if the period of warming up shall not be excessive. So, too, special cold winds beating on the exposed surfaces form additional heat-abstracting media, besides increasing the amount of cold air entering the building through the pores of the materials, and through the ordinary cracks and crevices of well-constructed buildings.

In connection with calculations for heat transmission by means of the coefficients here presented, the German government prescribes that computations be made on the basis of the following assumed lowest temperatures:

External temperature,		4° F.
Assumed lowest temperature of non-heated cellar and other portions of building permanently non-heated,		32° F.
Vestibules, corridors, etc, non-heated, and at frequent intervals in direct contact with external air,		23° F.
Air spaces between roof and ceiling of rooms,	Metal and slate roofs,	14° F.
	Denser methods of roofing, such as brick, concrete, etc.,	23° F.

As the temperature to be attained in rooms of various kinds, the German government prescribes for:

Stores and dwellings,	68° F.
Halls, auditoriums, etc.,	64° F.
Corridors, staircase halls, etc.,	54° F.
Prisons, occupied day and night,	64° F.

[*To be concluded.*]

CHEMICAL NOTES.*

By Jos. W. Richards, Ph.D.

Specific Gravity of some Fused Salts.—In the production of aluminium, as at present carried out, calcined alumina is dissolved in a bath of fused cryolite, or fused cryolite plus aluminium fluoride, and an electric current passed through from carbon electrodes. Whatever are the reactions which take place whereby the aluminium is liberated, the final result is simply the liberation of aluminium at one pole and oxygen at the other, as long as the bath is kept supplied with all the alumina it can dissolve. The following train of thought suggested itself to the writer: If the specific gravity of aluminium is 2·7, and that of cryolite 3·, how is it that molten cryolite floats on top of molten aluminium?

In order to get the specific gravity of the fused materials, a tight iron mould was taken and carefully measured. It was then filled level with the different molten salts, and from the weight of the salt and the computed volume of the mould, the specific gravity was calculated.

The following results were obtained:

	Specific Gravity.	
	Molten.	*Cold after Fusion.*
Commercial aluminium,	2·54	2·66
Commercial cryolite from Greenland,	2·08	2·92
Cryolite which contains all the alumina it can dissolve,	2·35	2·90
Cryolite + aluminium fluoride added in such quantity as to make a salt of the formula Al_2F_6. 2NaF,	1·97	2·96
Same as above, but containing all the alumina it can dissolve,	2·14	2·98

It can, therefore, be seen that while aluminium itself expands comparatively little in melting, the salts from which it is made expand from one-fifth to nearly one-third

* Presented at the meeting of the Chemical Section, held April 17, 1894.

of their volume, and, therefore, while heavier than aluminium when cold, they are lighter than aluminium when molten.

An Instructive Case in Thermo-Chemistry.—The writer endeavored to decompose a solution of ferrous sulphate by boiling it with finely-ground calcium carbonate, thinking that the following reaction might take place, precipitating the iron:

$$FeSO_4 + CaCO_3 = FeO + CaSO_4 + CO_2$$

The boiling was continued an hour, without a trace of ferrous oxide being precipitated.

The experiment was repeated with magnesium carbonate, thinking that the solubility of the magnesium sulphate might assist the reaction. The result, however, was similar to the first.

Thinking that possibly the decomposition would take place if the carbonic acid were first driven from the reagent by heat, the experiments were repeated with milk of lime and milk of magnesia. The precipitation of the iron was at once evident, showing that the expectation was correct.

Casting up the thermal data of the reactions involved, the figures show exactly why the reactions failed in the first instance and succeeded in the second.

$FeSO_4.Aq + CaCO_3 = FeO.Aq + CaSO_4 + CO_2$

Heats of formation, . . . 235,600 270,410 68,280 320,040 96,960

506,010 485,280

Deficiency, ... 21,730 calories.

$FeSO_4.Aq + MgCO_3 = FeO.Aq + MgSO_4.Aq + CO_2$

Heats of formation, . . . 235,600 267,600 68,280 322,580 96,960

503,200 487,820

Deficiency, ... 15,380 calories.

$FeSO_4.Aq + CaO.Aq = FeO.Aq + CaSO_4$

Heats of formation, ... 235,600 149,460 68,280 320,040

385,060 388,320

Excess, ... 3,260 calories.

$$FeSO_4.Aq + MgO.Aq = FeO.Aq + MgSO_4.Aq$$

Heats of formation, ...	235,600	148,690	68,280	322,580
	384,560		390,860	

Excess, ... 6,300 calories.

To find out why one has failed, and to predict where one may succeed, might be more frequently the office of thermochemistry, if better understood and more frequently applied.

Anthracite Coal in Bucks County, Pa.—The writer found, in 1892, a thin seam of anthracite coal at Hartmann's iron ore mine, one and one-half miles south of Hellertown, on the Springtown Road. The Saucon Valley, in which this mine lies, is a limestone pocket, surrounded by the syenitic ridges of the South Mountain, which have a general trend of southwest to northeast. The mine occurs at the junction of the limestone and granite, at the foot of one of these ridges. The ore is argillaceous siderite. The coal is found in a seam about one-eighth to one-quarter of an inch in thickness, overlying the iron ore and embedded in brown clay, which is somewhat indurated near to the coal. At the point where the specimens were dug out, the coal was within a few feet of the surface. Every indication pointed to it being a true occurrence, found *in situ*, as the clay bank out of which it was dug had apparently never been disturbed. The coal is true anthracite, burning before the blowpipe without any yellow flame to a reddish-brown ash.

LEHIGH UNIVERSITY,
BETHLEHEM, PA., April 17, 1894.

On the Analysis of American Refined Copper.*

By Harry F. Keller, Ph.D.

It is generally conceded that the presence even of minute quantities of other elements in metallic copper has a marked influence upon its physical properties, and especially upon its electric conductivity.

The copper produced in the Lake Superior region is relatively free from injurious admixtures, and is therefore generally preferred when a high conductivity is desired. "Lake" copper is always quoted a trifle higher than the metal from other localities.

Of late years the production of copper from impure sulphide ores has grown enormously, and, at the same time, the quality of the product has steadily improved. It has, indeed, become possible through the introduction of the Manhés converter and the electrolytic process of refining, to obtain from matte a metal nearly, if not quite, as pure as the native of Lake Superior. Unfortunately, it appears that the very slight traces of the impurities retained in it affect the conductivity to a greater extent than is the case in the best lake copper. Silver and iron are the chief impurities of the latter, while electrolytic copper not infrequently contains small quantities of bismuth, antimony, arsenic, selenium and tellurium.

That the exact manner in which these elements affect the physical properties of copper is not better understood, is undoubtedly owing to the lack of rapid, and at the same time, accurate, methods of ascertaining their relative amounts. It is astonishing to note that the works on quantitative analysis published in the English language entirely neglect copper analysis. To my knowledge the important contributions to this subject by Hampe, Fresenius and other German chemists have not been translated.

* Read at the stated meeting of the Chemical Section, held June 19, 1894.

For several years past I have given considerable attention to this subject. My analyses include the metal from the Lake mines, as well as copper obtained from Western mattes.

To the former, I found Hampe's original method* of analysis well adapted. This consists essentially in precipitating, by electrolysis, the greater part of the copper, and separating the metallic impurities in the usual manner from the remaining solution. The non-metallic elements, such as oxygen and sulphur, are determined in separate portions of the sample.

For obvious reasons it is not desirable to employ this method in analyzing electrolytically refined copper. Accurate results can be obtained by following the plan proposed by Fresenius,† but the separation of large quantities of copper by means of hydrogen sulphide, and the difficulty of accurately weighing bulky solutions, render this method very objectionable. A far more convenient process is the one recently published by Professor Hampe.‡ It is also more rapid than either of the two methods mentioned, and, with some modifications, it is especially well adapted for the analysis of most of the American refined coppers.

The process depends upon the removal of most of the copper as cuprous sulphocyanate.

The manner in which I practise it is briefly as follows:

25 grams of material are placed in a tall, lipless beaker and treated with a mixture of 200 cubic centimeters of water, 45 to 46 cubic centimeters of nitric acid (specific gravity 1·21), and 25 cubic centimeters of concentrated sulphuric acid (in case that much antimony or bismuth is present, as much as 100 cubic centimeters of H_2SO_4 may be taken). The beaker is covered and heat applied until nitrous fumes are no longer given off and the solution then diluted with 200 cubic centimeters of water to prevent the separation of copper sulphate. A rapid current of sulphur dioxide is now conducted into the liquid, the temperature of

* Zeitschr. f. Berg, Hütten u. Salinenwesen **21**, 218, and **22**, 93.

† Zeitschr. f. analyt. chem., **21**, 229.

‡ Chemiker Ztg., 1893, **92**, 1691.

which is maintained at about 40° C. When the nitric acid is destroyed and the red fumes have disappeared, the liquid becomes turbid, owing to the precipitation of silver, selenium and tellurium. To insure the complete separation of the silver, a drop or two of hydrochloric acid may be added. After standing for twenty-four hours in a warm place, the solution is poured through a small filter into a graduated flask of two liters capacitv. It contains bismuth, antimony, arsenic, iron, also nickel and cobalt, if these are present in the sample.

The sediment retained by the filter is composed of gold, silver, silver chloride, selenium, tellurium, possibly also lead sulphate, and traces of bismuth and antimony.

To determine the elements in the filtrate, the greater part of the copper must first be removed. To this end a measured amount of standard potassium sulphocyanate solution (1 cc. = ·05 Cu) is gradually added, whilst a current of sulphur dioxide is passed into the liquid. An excess of the sulphocyanate should carefully be avoided; it is preferable to leave some of the copper in the solution which should now emit a perceptible odor of sulphur dioxide. The delivery tube is withdrawn and rinsed off into the flask, the contents of which are then made up to the mark. To effect a thorough mixing it is well to pour the contents into a dry beaker, and to re-transfer them several times from one vessel to the other. The precipitate is allowed to settle and an aliquot portion, say 1,800 cubic centimeters, of the solution, filtered off. The separation and estimation of the different metals is effected according to the usual analytical methods. It is hardly necessary to state that the sulphur dioxide must be expelled before hydrogen sulphide is passed into the liquid.

In calculating the amounts of the metals contained in the entire liquid, we must allow for the volume occupied by the precipitate. According to Hampe the specific gravity of the sulphocyanate is nearly 3, and since twenty-five grams of copper would give about forty-eight grams of this salt, the volume of the latter would be sixteen cubic centimeters. The actual volume of the solution, therefore, is

2,000 — 16 = 1,984 cc. Suppose *e. g.* we had filtered off 1,800 cubic centimeters, and found in it ·020 gram of arsenic, then

$$\frac{1984 \times \cdot 02}{1800}$$

would be the amount of arsenic in the sample taken.

There yet remains to describe the analysis of the insoluble portion from which the main solution was filtered. It may contain, as I have already said, gold, silver (both in the metallic state and as chloride), selenium, tellurium, lead sulphate, and traces of bismuth and antimony, occasionally also copper.

It is best to detach, as completely as possible, the dry mixture from the filter, and to destroy the latter with fuming nitric acid in a small porcelain casserole. The detached portion is then added, and treated with the nitric acid till completely oxidized. After evaporation on the water-bath of the free nitric acid, the residue is digested with dilute hydrochloric acid, which leaves the silver in the form of chloride. This is filtered off, purified, and determined in the usual way. From the filtrate, selenium and tellurium may be thrown down by means of hydroxylamine hydrochloride. In the cold this reagent seems to have little effect, but upon warming, a reddish turbidity is observed which gradually collects in the form of dark flakes. These represent all the selenium and tellurium; they are collected on a tared filter, and dried at 105°-110° C. to constant weight.

I have not been able to effect a clean separation of the two elements. Approximate estimations were made by fusing the mixture in a current of hydrogen with potassium cyanide; the aqueous solution of the fused mass was then exposed to the air, which caused most of the tellurium to separate.

Gold, lead, and the traces of antimony and bismuth are obtained by the ordinary methods.

SMOKE-PREVENTING APPLIANCES.*

W. F. SICARD.

The attention of the writer having lately been called to the subject of smoke prevention, and becoming much interested in it, he has chosen this for the subject of a paper, thinking that it might interest the members of this section to discuss some of the devices proposed for this purpose.

While there seem to be an almost infinite number of devices for the prevention of smoke, many of them, if not nearly all, are practically untried. It is true that for nearly all the systems before the public, the inventors base their claims of efficiency upon the results of practical tests, but they are not always to be depended upon. It is by the results of continuous service, more than by special test that the merits of such an invention are proven, and it is usually the case that that system or device, for whatever purpose it may be, which is in the most general use is the best.

The question of the combustion of smoke, or, more properly, the prevention of smoke, is one of great interest to the engineer. The increased efficiency that will result from a more complete combustion of the fuel fed to a furnace, makes it an important object to scientific men to contrive some device whereby this end may satisfactorily be attained, and which, accordingly, must be simple, economical, durable and susceptible of regulation and control. That there are many inventors who claim to have solved this problem, the records of the Patent Office will attest, and doubtless many of them in a greater or less degree have done so, or at least have increased the efficiency of the particular boiler upon which they experimented.

There is such a vast difference, however, in the very foundations of their claims, and at the same time such a

* Read at the stated meeting of the Section of Engineers and Naval Architects of the Franklin Institute, May 23, 1894.

sameness in their results, and the methods of attaining those results, that one is almost bewildered. There are smoke preventers of every conceivable kind and variety, some of them simple, the greater number complex. There is no doubt that a cheap, simple and durable system that would give satisfactory results would be in demand, for in the fierce competition of these days every money-saving device must be employed. Of those at present on the market many are inefficient and practically untried. So many inventions are brought out before it has really been shown and proven that the results from their use are a gain or a loss, that manufacturers naturally hesitate before trying a new thing. Also, many of these systems are so exceedingly complex as almost to require the services of a man specially trained to operate them.

Smoke is defined for us as the combustible and uncombined products, produced in the imperfect combustion of coal, and which pass off from a furnace by way of the flues. Its principal constituents, and the only ones we need notice just now, are the portions of hydrogen and carbon of the fuel gases, that by reason of an insufficient supply of oxygen, have not been transformed into steam and carbonic acid, the ultimate products of the complete combustion of carbonaceous fuel. The hydrogen and partially burned carbon thus given off are invisible, but much of the carbon, when separated from the hydrogen in furnaces of faulty construction, changes from the gaseous to the solid state and becomes visible as a black, sooty body.

Coal is composed of a number of substances; the main constituents of all coal, however, are carbon and hydrogen, and these two in various combinations constitute the bituminous portion from which are derived the volatile products given off in the combustion of coal. The principal portion, however, is composed of carbon. The bituminous part of carbonaceous fuel becomes available for heating purposes only after its conversion to the gaseous state, while the carbonaceous portion is available in the solid state.

Carbon is susceptible of uniting with oxygen in two pro-

portions, by which two distinct bodies, possessing distinct chemical properties, are formed. These bodies are carbonic oxide and carbonic acid. One of the most important facts revealed by the analysis of coal is the large proportion of hydrogen which bituminous coals contain. This may be roughly estimated at from five to six per cent., and it forms the main element of the evolved gases by the combustion of which flame is produced. Where coal is exposed to heat in a furnace the bituminous portions are volatilized and pass off. At the lowest temperature various condensible hydrocarbons are evolved. At the highest temperatures of distillation, permanent hydrocarbon gases and hydrogen are given off. After this distilling process, all that remains in the furnace is the fixed or solid carbon of coal, called coke, and mixed with it, earthy matter, the ash of the coal. The fixed carbon or coke remaining in the furnace after the volatile portions of the coal are given off, averages about sixty per cent. of the gross weight of the coal. As stated before, the hydrocarbons given off at the lowest temperatures, being richest in carbon, constitute the flame-making element of the coal.

A charge of coal, thrown upon a furnace fire, does not increase the general temperature, but lowers it and generates gases. On account of the amount of heat that is converted from the sensible to the latent state in this process, volatilization is a cooling process. So long as the bituminous constituents of coal are being evolved in quantity, the carbonaceous portion remains comparatively cool and useless as a heating agent. In short, the carbonaceous part has to wait for the heat required for its combustion until after the bituminous portion has been consumed.

The ratio of heating effect in the perfect combustion of coal compared with that evolved in imperfect combustion may be stated as about 15 to 4·5. Carbonic oxide is the result of imperfect combustion, and carbonic acid the result of perfect combustion of carbon. Combustion means union; in other words, the union of a combustible body with a supporter of combustion, in this case oxygen. At this point it may be interesting to note that

coal gas is not inflammable; for by itself it cannot produce flame or support combustion in other bodies. A lighted candle in an atmosphere of coal gas will be extinguished.

Effective combustion for practical purposes depends more upon the air than the gas. This is so because we cannot control the gases while we can control the air that we supply to the furnace, and it is this control of the air that is the foundation of nearly all smoke-preventing devices. A good example of the unburnt gases in a flame is afforded by the common candle. In this, the tallow is first melted, then drawn up through the wick, and changed to a vapor, which has its temperature raised high enough to cause it to combine with the oxygen of the air, the heat of the combustion causing the separated carbon particles to become heated to brilliant whiteness. Around the outside is a filmy flame of this vapor and in the middle of it is a portion of gas which cannot be burnt for want of oxygen, which has no chance to reach it. If we supply oxygen to this flame by means of a blow-pipe, we greatly increase its temperature. In furnaces with natural draught, the volume of air required exceeds that required when the draught is produced artificially; an insufficient supply of air causes imperfect combustion, though an excess in the supply of air means a waste of heat. With very slow and uniform rates of combustion, nearly all the air required may be drawn through the grate; but if the rate of combustion be high, a great part of the air must be fed to the fuel above the grate, to consume the gases generated.

There are numerous cases in which, while dense smoke is given off with the furnace door closed, if it be opened slightly a great improvement in this respect will be noticed. At the same time, it has been conclusively shown, in certain classes of boilers, that while in realizing the highest power of a gaseous coal smoke is prevented, yet, in realizing the highest power of the boiler, smoke is made. The proportion of surplus air, the presence of which is required for the combustion of coal in ordinary furnaces in excess of the quantity which is chemically consumed, is diminished as the rate of combustion is increased, and the diminution of this

excess is one of the reasons why the temperature of the furnace rises as the rate of combustion increases. This is shown in the following tests, the figures being from four different tests of different boilers and coals:

	Coal per square foot of grate per hour.	*Surplus air.*
Test 1, ...	2 to 4 pounds.	100 per cent.
Test 2, ...	7 pounds.	100 per cent.
Test 3, ...	10 to 16 pounds.	25 to 50 per cent.
Test 4, ...	20 pounds and upwards.	9 per cent.

In ordinary practice the rate of combustion for anthracite coal is from 7 to 16 pounds, and for bituminous coal 10 to 12 pounds, and with artificial or forced draught with blower, exhaust blast or steam jet, the rate may be increased from 30 pounds to as high as 120 pounds. It has been shown that in the marine boiler from 20 to 32 per cent. of the total heat of combustion is expended in producing the chimney draught, and, if we add to this the losses which will result from incomplete combustion and dilution of gases by excess of air, it will bring the total loss up to nearly 60 per cent.

From the foregoing statements, which express the results of practical tests, we are led to the conclusion that the cardinal principle of all smoke-preventing devices is, that in order to achieve complete combustion, and thus prevent the formation of smoke, the gases produced and air supplied must promptly and thoroughly be mixed. We have spoken of the relative volume of air required in natural and forced draught, and also of the various rates of combustion. In regard to the place of admission, above the grate, it has been found by test that the admission of air at the bridge of the furnace gives about 2½ per cent. better results than when it is admitted at the front of the grate. If the grate be not equally well covered with coal, the air admitted will enter in irregular streams through the uncovered parts, and be restricted at the time when it will be most needed. Of course, under such conditions, it bids defiance to all control and regulation, and as all that we can do towards effecting perfect combustion depends upon regulating the supply of air, the importance of having the coal on the grate well and evenly distributed is evident.

We will now proceed to consider some of the devices that have been proposed for smoke prevention.

In the first system which we will look into, the inventor states that his invention relates more particularly to obtaining practically perfect combustion of fuel in a boiler furnace, and to increasing the steaming capacity of the boiler, by preventing loss by the too free escape of heated gases, thus effecting economy in the use of fuel. He argues that heretofore the efforts that have been made to effect perfect combustion by means of forced draught have failed, because either too much or too little air under pressure was introduced to effect the required combustion, and because the heated products of combustion, principally carbonic acid gas

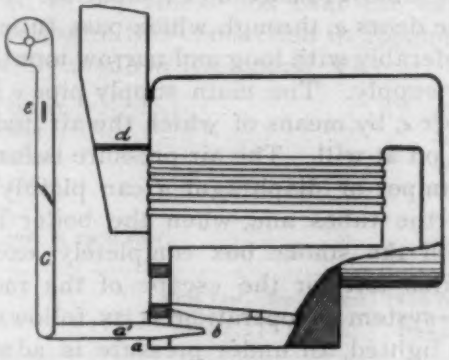


FIG. 1.

and the nitrogen, the latter constituting the incombustible element of the air introduced, were allowed to escape too freely and at too high a temperature, thus carrying away the heat which should have been communicated to the water in the boiler and used to make steam. In this system the boiler is provided with a tight ash-pit and a tight furnace. Into the ash-pit is introduced a sufficient quantity of air under pressure to properly combine with the fuel, and no more. To prevent a waste of heat the smoke box is closed directly above the tubes, leaving only an opening of restricted but regulable area for the escape of the products of combustion. Into the furnace is introduced the proper quantity of air for the purpose of supporting combustion,

taking into consideration, and making proper allowance for, the nitrogen constituting the incombustible element of the air introduced under pressure, and taking from the furnace only the results of such combustion. To properly effect this result with a given weight of fuel per hour, the necessary volume of air to combine with this weight of fuel is introduced into the tight ash-pit, and the area of exit is adjusted in accordance with the principles stated. With this arrangement no chimney or stack is considered necessary, except when starting the fires, save such as shall serve to carry off the incombustible gases which reach the smoke box.

In the accompanying sketch, the parts are so easily distinguished as almost to need no explanation. The ash-pit is closed by the doors *a*, through which pass tubes *a'*, having nozzles *b*, preferably with long and narrow mouths, for delivering the air supply. The main supply pipe *c* is furnished with a damper *e*, by means of which the air under pressure may be shut off at will. The air pressure is furnished by a fan. The damper or diaphragm *d* can plainly be seen directly above the tubes and, when the boiler is steaming, this closes off the smoke box completely, except for the small apertures left for the escape of the incombustible gases. The system of operation is as follows: The fire having been lighted, air under pressure is admitted under the grate, the oxygen producing rapid combustion. Until the fire gains some headway, the damper *d* is left open, and the smoke and gas escape through the flues as in the ordinary system. As soon as combustion is fully established, the damper must be closed, thus closing completely the space between the tube sheet and the front door of the smoke box. There is still, however, an escape for the incombustible gases, through the holes in the damper before mentioned. By this means the stack is practically closed. The release of these incombustible elements is effected by the draught of the stack, as in ordinary practice, or by a steam blast, which may be placed, through the damper, to the base of the stack. This steam blast is considered necessary in the locomotive class of boilers, where rapid steam-

ing and consequently rapid liberation of these incombustible gases is required. The inventor claims to have found that the best results are produced by placing the damper in the smoke box, almost immediately above the upper row of tubes, so that the heated incombustible gases shall be detained, or temporarily held back in the smoke box and below the water line of the boiler, before they are finally delivered to the stack through the holes in the damper. All the units of heat, temporarily retained below the water line, are conducted to the water and help to make steam, while those carried above the water line have the effect of superheating the steam. On these grounds he bases the claim that the damper placed in the chimney is not the equivalent of a damper placed in the smoke box near the water line. It may be interesting in this connection to append the results of a test recently made in Richmond, Va.:

Diameter of boiler,	48 inches.
Length of boiler,	14 feet.
Number of tubes,	49
Diameter of tubes,	2·75 inches.
Grate surface,	20 square feet.
Duration of test in each case,	10 hours.

	First Test, without Blower.	Second Test, with Blower.	Third Test, without Blower.	Fourth Test, with Blower.
Pounds coal used during test,	1846·75	1771	1591	1377
Pounds water used during test,	12715·74	13608·89	10078·45	10967·72
At temperature of	95°	95°	84°	81°
Evaporation to steam pressure of	75 lbs.	70 lbs.	69 lbs.	73 lbs.
Water evaporated from 212° to steam at atmospheric pressure,	15667·5	16704·34	12215·06	13654·81
Water in pounds, evaporated per pound of coal,	8·48	9·73	7·84	9·91
Saving in coal,		12·84		20·88
Air pressure in inches of water,				·75

These tests show a saving in coal of 12·84 per cent. and 20·88 per cent., respectively, and the engineer in charge of the tests mentions that there was an almost total absence of smoke even immediately after firing.

The second system is not so simple, and you will notice its complete difference from the former one. The object of this system is to effect the perfect combustion of smoke and gases generated in the use of bituminous coal and simi-

lar fuels, and also to increase the steaming capacity of the boiler. The inventor, in his description, says that, as understood by those familiar with boiler furnaces, the fuel gases enter the flues from the fire box in a partially consumed condition, and it is found that the water surrounding the flues partially cools them, thereby extinguishing the flames and causing the gases to pass through the flues in the condition of smoke. In cases where the gases arising from the burning fuel come in contact with air of lower temperature, the ignition of such gases is prevented, or, if ignited, the flame is liable to be retarded or even extinguished. This, he says, may be overcome by properly heating the air and then admitting it to the furnace, under proper conditions and in proper proportions, so that a practically perfect combustion will be obtained. It is also important that such heated air be introduced at the proper place. If it be introduced too near the boiler flues, it will readily escape and the result sought for will be lost. If, however, it be introduced at a point remote from the boiler flues, as, for instance, from above the furnace door to a little beyond the center of the fire box and above the bed of the fuel, and also in the bed of fuel, almost perfect combustion is attained and the intensity of the flames is increased. This will give an indirect course to the heated air and a better opportunity for its mixture with the heated gases. Hence the value of fuel does not depend solely on the quantity of air supplied thereto, but also upon the condition of the air and the manner of its application. Working upon these assumptions, they have constructed their furnace so that, if desired, the air may be supplied in three volumes, one of which enters the fire box through the grate bars, generates the gases from the coal, as in a gas producer, and partially consumes them. The other volume of air, which has previously been heated, enters through an air duct directly into the mass of burning fuel, mingling with the generated gases and partially consuming them, while the remaining volume of air, having also first been heated by passage through a coil of pipe over the fire box, enters the fire box, preferably at a point remote from the boiler flues, and mixing with the partially con-

sumed gases completes their combustion and produces intense heat. The means employed for heating and introducing the air into the fire box are also utilized to increase the steaming capacity. For illustration, let us employ the sectional view of a locomotive boiler. The boiler is of the usual construction, with fire box, door for feeding fuel, grate bars and tubes, as placed in ordinary practice. In the fire box, arranged parallel to each other are an upper and lower series of water protected air tubes, extending from the tube

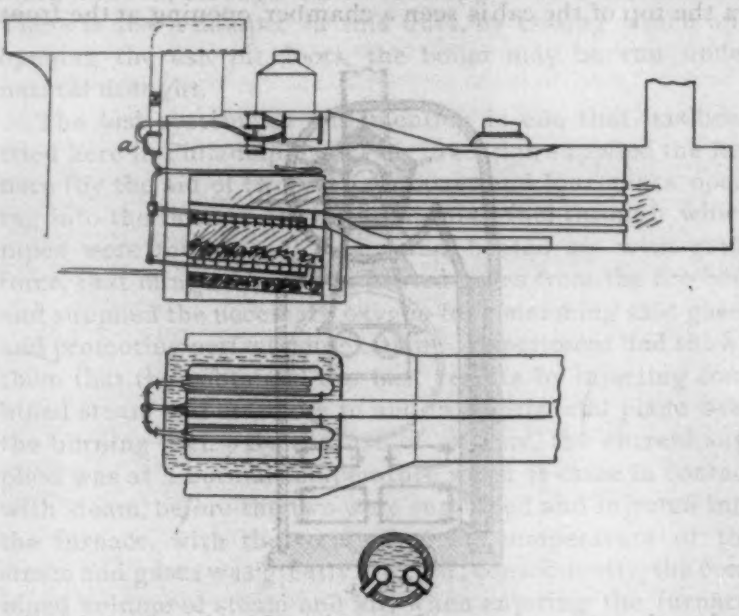


FIG. 2.

sheet to above and below the door. As shown in the detail, they are practically three tubes combined in one. The smaller tubes are inside the larger one, and extend nearly the length of the fire box. They are secured within the larger tube by a series of plugs or nipples, about two inches apart. These plugs are first driven through perforations in the tubes, and there bored out, thus forming a passage for the delivery of air, at the same time securing rigidly together the three tubes. The center tube of the upper series will be noticed to extend forward nearly

to the forward tube sheet, resting on the bottom shell of the boiler. This continuation conveys the cooler water immediately from the front, to and through the water jacket of the tube with which it is connected, quickly heating the same and enabling the boiler to rapidly generate steam. If desired, the ash pan may be entirely closed, and air furnished by the lower series of air pipes, which are directly in the bed of fuel, and thereby preventing the red-hot coals from dropping along the roadway. In the top of the cab is seen a chamber, opening at the front

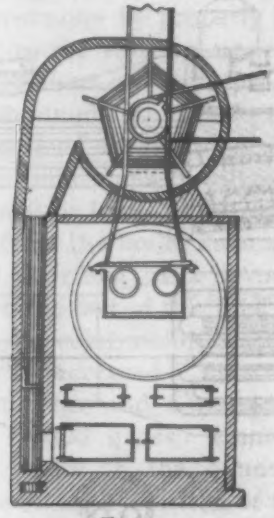


FIG. 3.

end to the atmosphere. Connecting this chamber with the air system is a pipe with an automatic valve, *a*, which cuts off connection between the chamber and system when air is being fed from the reservoir. The reservoir, suitably placed, is supplied with an air pump, and is also connected with the system at the automatic valve. Over the fire box is a coil of pipe, passing through which the air is heated on its way to the fire box. A serious objection to locomotives equipped with air-feeding mechanism is that when the locomotive is at a standstill the air supply ceases. In this case the objection is claimed to be obviated for the reason that

the air pump and reservoir can be thrown into action when the engine is not moving.

The third system is again quite different from the others. The above sketch shows the boiler with stack and ash pit doors. On top of the boiler and in rear of the stack is a fan, connected to the stack by a duct or neck. The smoke and gases are drawn into the fan and forced down the side pipe into the ash pit. There is a door in the duct between the stack and fan, through which the supply of air is admitted. There is also a damper in this duct, by closing which and opening the ash pit doors, the boiler may be run under natural draught.

The last system we will mention is one that has been tried here in Philadelphia. This invention supplied the furnace (by the aid of two vacuum boxes and four pipes opening into the furnace above the burning fuel through which pipes were introduced) steam and heated air with great force, that mingled with the heated gases from the fire bed, and supplied the necessary oxygen for consuming said gases and promoting perfect combustion. Experiment had shown them that they obtained the best results by injecting combined steam and air, close to and in a horizontal plane over the burning fuel. By the use of *cold* air, the current supplied was at a normal temperature when it came in contact with steam, before the two were combined and injected into the furnace, with the result that the temperature of the steam and gases was greatly lowered; consequently, the combined volume of steam and air, when entering the furnace, was not at so high a temperature as it should be to effectually mingle with and ignite the gases. The necessity was thus demonstrated of using *hot* air, as the rising products of combustion would only ignite at a very high temperature. The air was heated, before entering the furnace, by a series of pipes containing auxiliary hot air vacuum chambers beneath the grate bars. This arrangement was tested here some years ago in the *Record* building. The results of the test were as follows:

	Day Run.				Night Run.			
	With Attachment.		Without Attachment.		With Attachment.		Without Attachment.	
	Boiler 1.	Boiler 2.	Boiler 1.	Boiler 2.	Boiler 1.	Boiler 2.	Boiler 1.	Boiler 2.
Coal used in pounds,	840	840	1,260	1,260	1,122	1,176	1,680	1,680
Average steam pressure,	64	64	58 to 60	55 to 60	63¾	—	57 to 58	—
Ashes in pounds,	111	106	253	268	152	147	266	260
Water gauge,	2½	2⅝	2½	2⅝	2½	2½	2½	2½
Total coal used with attachment,		1,680 pounds.				2,298 pounds		
Saving in favor of attachment,	840 pounds or 33⅓ %.				1,062 pounds or 31⅛ %.			

Two boilers, 80 horse-power each, running a Corliss engine. Length of boilers, 12 feet; diameter, 40 inches. Twenty-eight 4-inch tubes. Fire space, 42 x 60 inches. Fire box, from sheet of boilers to grate, 18 inches.

The four systems here described will suffice to illustrate how totally different are the ideas of their respective inventors, as regards the means to be employed in reaching the same end. Briefly summed up, they are as follows: The first supplies air under pressure; the second supplies heated air in a manner totally different from the first; the third essays to pass the smoke and gases through the furnace a second time; and the fourth supplies hot air and steam. Whatever be our opinions of the relative merits of these systems, they will afford us ample opportunity for discussion.

SHORTENING THE TIME FOR CORRECT SOUNDING.*

By F. M. F. Cazin.

When sounding is considered necessary, the ship's safety may depend on the shortness of time within which correct soundings can be made. If it were possible to correctly ascertain the depth of water below ship at the very instant when the lead strikes, and without relying on marks and deeps inserted in the sounding line, that is, without relying

*Read by title at the stated meeting of the Section of Engineers and Naval Architects, April, 1894.

on correct observation of their color and correct counting of their number, when the line is hauled in; if the requirements of observation and action could be reduced to two signals, the one by the captain and the other by the man handling the line—the one being a command to let the lead, held at the water's surface, drop, and the other announcing that the lead has struck bottom—the interval between the two observed on the captain's time-piece telling at once the sounded depth, then precious seconds might be saved, on which the ship's fate is possibly depending.

Such a possibility does exist, and the method of sounding that involves such a saving of time, when compared with present practice, has the further advantage of being both more convenient and more reliable, on account of being more simple, involving fewer causes for possible error, and relying on the observation mainly by the captain personally.

It is the purpose of these lines to demonstrate the possibility as stated, and to recommend its acceptance in practice jointly with the use of adequate standard tools in its execution.

The only tools required are a lead for shallow and normal depths, each of known density relative to the water of navigation and of precisely known length, both being accompanied by a pocket-tablet with figures for reference, which figures are of such nature as easily to impress themselves on the memory; the standard of leads being so selected that these figures remain of an uncomplicated kind.

In order not to unduly expand this statement, I must refer to some previous publications.

In the issues of the *Journal of the Franklin Institute* of March, April and May, 1893, the author stated and rendered proof of a natural law by him newly discovered, relating to the resistance by a liquid or gaseous medium to the movement of a solid therein. This law shows that a solid, when moving in a medium, causes a stated quantity of the medium to move in a direction inverse to the movement of the solid; and the law shows this quantity of the medium moved inversely, to be as the product of the volume displaced by

first immersion by the distance of travel divided by the length of the solid, such length being measured in the direction of relative motion, and the distance, for which this stated quantity of the medium is moved inversely, is shown to be as the length of the solid, measured in the direction of relative motion. By introducing into theoretical mechanics the (also) new value

$$\frac{B}{d} = \frac{\text{Buoyancy}}{\text{Length}}$$

for "transverse average section," the newly discovered law was made serviceable for measuring the resistances to motion of ship, and the theoretical power required for propelling her. And it was also shown that aside of the quantity of the medium permanently and inversely moved by the movement of ship another stated quantity* of the medium is moved by the motion of ship, such other quantity returning to the position previously occupied without exercising any resistance or increasing power-requirement.

And finally, the author stated, as evolved from the same natural law, an equation

$$v = C = \sqrt{2\,g.\,d.\,\delta.\,\frac{\delta - 1}{\delta + 1}}$$

for the ultimate and uniform velocity with which any solid of higher specific gravity than the medium will finally fall in such medium.

This equation, having a direct bearing on the mechanical treatment of the ores of metals and on coal washing, the author dealt with, and with the practical consequences that must be drawn from it in metallurgical practice, in a paper "On Solids Falling in a Medium. I and II," published as part of the twenty-fourth volume of the "Transactions of the American Institute of Mining Engineers."

To the last-mentioned publication (generally accessible in pamphlet form) the author refers for the demonstration in detail of the correctness of the last stated equation.

---

*This quantity is the product of the length of travel by the difference between the transverse major section of the solid and its transverse average section, which latter is as the immersed volume divided by its length, such length being measured in the direction of relative movement.

It was obtained by balancing the *inherent potential gravity* as cause of acceleration in the fall of a solid, expressed by

$$B \,.\, \delta \,.\, v \quad \text{Kgm—ms}$$

with the resistance by a medium to such fall, such fall resulting first in a modification of the acceleration g by

$$p = \frac{Q - P}{Q + P} = \frac{\delta - 1}{\delta + 1}$$

when

$$Q > P \text{ and } \delta > 1$$

as proven by the analogy with Attwood's results, when a weight in its fall raises a smaller weight, *such resistance to immersed fall* being determined by the new law, and the thereto truly relating Attwood law, and being then correctly expressed by

$$R = y \,.\, \frac{B}{d} \,.\, v \times \frac{v^2}{2g \times \dfrac{\delta - 1}{\delta + 1}} \text{ kgm — ms.}$$

B signifying buoyancy or displacement by first immersion.

d signifying length of solid, measured in the direction of relative motion.

v signifying velocity per second.

y signifying 1,000, as changing cubic-meters or metric tons, in which the value B would otherwise appear, into kilograms, and in consequence the total value into kilogram-meters, all values for distance, area or volume being expressed in meters.

δ signifying density of the solid.

For present purpose it is sufficient, if the statement is made that the distance any solid will fall in a medium with modified acceleration

$$= g \frac{\delta - 1}{\delta + 1}$$

(if, on account of higher density, it falls at all), is as

$$d \,.\, \delta$$

this is the distance, within which it causes to move inversely (this is to ascend) its own weight of the medium for the

distance of its own length, and that the aggregate velocity with which this limited distance is passed is only one-half of the ultimate *uniform* velocity of submerged fall, or

$$\frac{v}{2} = \frac{C}{2} = \frac{\sqrt{2g \cdot g \cdot d \cdot \delta \cdot \frac{\delta - 1}{\delta + 1}}}{2}$$

such ultimate uniform velocity of submerged fall being for solids of any one specific form closely adapted in its longitudinal lines to the molecular division lines of the medium, as

$$C = \sqrt{2 \cdot g \cdot d \cdot \delta \cdot \frac{\delta - 1}{\delta + 1}}$$

Of these two equations I propose to take advantage in a new method for sounding.

We may assume a sounding lead in the form of a cylinder with pointed ends, inclosed in a copper shell, being 0·1 m. long (d as one decimeter). The density relative to sea water is assumed as 11.

Such a lead will fall a distance

$$d \cdot \delta = 0{\cdot}1 \text{ m.} \times 11 = 1{\cdot}1 \text{ m.} = 3{\cdot}6 \text{ feet.}$$

with a velocity of

$$\frac{C}{2} = \frac{\sqrt{2g \cdot d \cdot \delta \cdot \frac{\delta - 1}{\delta + 1}}}{2} = \frac{\sqrt{19{\cdot}62} \times \sqrt{0{\cdot}10} \times \sqrt{11 \cdot \frac{10}{11}}}{2} =$$

$$= \frac{4{\cdot}43 \times 0{\cdot}316228 \times 3{\cdot}028}{2} = \frac{4{\cdot}24 \text{ m.}}{2} = \frac{13{\cdot}9 \text{ feet}}{2} = 6{\cdot}95 \text{ feet.}$$

This means that the lead will first fall a distance of 3·6 feet, with a velocity of $2\frac{1}{8}$ ms. or 6·95, virtually 7 feet, per second, or will use the first 1·1 / 2·12 or very nearly 0·5 second in falling 2·12 / 2 or $1\frac{1}{16}$ ms., or, as stated, 3·6 feet. And thereafter the distance will increase at the rate of 14 feet per second, giving for the first $1\frac{1}{2}$ second of fall from the surface of the water a depth of $17\frac{1}{2}$ feet.

But the time for observation relating to the same depth may be materially prolonged by selecting a lead of equal

length but of lower density, the shell being only partly filled with metal.

Or even both length and density may be lessened, thereby causing longer time to be required for falling the same depth.

For a lead with d as 0·1 m. and as 6·4, we find the ultimate uniform velocity of submerged fall as

$$\sqrt{2g} \times \sqrt{d} \times \sqrt{\delta} \times \sqrt{\frac{\delta - 1}{\delta + 1}} = \sqrt{19{\cdot}62} \times \sqrt{0{\cdot}1} \times \sqrt{6{\cdot}4} \times \sqrt{\frac{5{\cdot}4}{7{\cdot}4}} = 4{\cdot}43 \times 0{\cdot}316 \times 2{\cdot}53 \times 0{\cdot}8544$$

$$= 3 \text{ ms.} = 9{\cdot}84 \text{ feet.}$$

But a distance $d \cdot \delta = 0{\cdot}1 \cdot 6{\cdot}4 = 0{\cdot}64$ m., or 2·0992 feet. (2·1), is first fallen with a velocity of 9·84 / 2 or 4·92 feet, or 2·1 / 4·9 or 3 / 7 = 0·43 second are spent in the fall of 2·1 feet. And for every second of prolonged fall the depth from surface is greater for 9·84 feet.

Comparison may then be made between the action of the heavier and the lighter lead of the same length.

The heavier lead will reach a depth of 50 feet, using

	0·5 second	for falling	3·5 feet, and
46·5 / 14 or 3·3	"	"	46·5
this is 3·8	"	"	50·0 feet of depth.

But the lighter lead will indicate the same depth, using

	0·43 second	for the first	2·1 feet, and
47·9 / 9·84 or 4·86	"	remaining	47·9 feet
using 5·39	"	entire	50·0 feet

It is thus shown that, of the two leads of the same length but of different densities, the one of lower density requires 1·59 seconds more for reaching a depth of fifty feet, a difference, which further calculation shows to be increased at a depth of 100 feet to 10·38 — 6·7 or 3·68 seconds.

This difference in time required for falling a stated distance may be further increased by reducing aside of density

also the length of the lead employed. With 0·06 for "d" we find by

$$\sqrt{0{\cdot}06} = 0{\cdot}245 \text{ and } 4{\cdot}43 \times 0{\cdot}245 \times 2{\cdot}53 \times 0{\cdot}8544 = 2{\cdot}346 \text{ ms.} = 7{\cdot}69488 \text{ ft.}$$

as the ultimate and uniform velocity of fall. And with $d \cdot \delta$ as $0{\cdot}06 \times 6{\cdot}4 = 0{\cdot}384$ m = 1·26 ft. as distance for incipient fall with modified acceleration with an aggregate velocity of $7{\cdot}7 / 2 = 3{\cdot}85$ ft. per sd.; the time spent therein appears as $1{\cdot}259 / 3{\cdot}847 = 0{\cdot}33$ second.

This lead, therefore, will use in falling:

	3·85 feet		0·33 seconds
and for falling	46·15	46·15 / 7·7 or	6·00 seconds
or for falling	50· feet	will use	6·33 seconds

or 2·53 seconds more than the heavier and longer lead.

And calculation will show that, for a distance of fall of 100 feet, this difference will be increased to 12·82 — 6·7, or to 6·12 seconds; the lighter and shorter lead using almost double the time of that used by the heavier and longer one.

By varying the values for density and length, well adapted standard-leads may be selected for the use of navigators, that comply fully with all practical requirements, and the author would with pleasure assist makers of nautical instruments in perfecting such standard-leads under the protection of his rights as inventor.

Provided with such leads for sounding by time, the captain, with his time-piece in hand, may give the command, "Drop," by signal to the man holding the lead near the surface of the water, and the man may, by lifting one of his hands or by call, signal the instant when the lead strikes bottom, and the interval of time between the two signals, as observed on the time-piece by the captain, will at once tell the depth of water below surface, the captain having in his memory a few simple figures or consulting a pocket-tablet instead.

Except in time required, the old and new methods vary

in this also, that under the older method the length of line spent is exclusively relied upon, while the spending of this length depends on other conditions also, besides the depth of water, while under the new method this cause of error is avoided, and a more reliable basis of conclusion is utilized, namely, that of vertical fall and time spent therein, which is regulated by a law of nature independently of all causes of error, as long as free fall is resisted by the water only and not by any action of the sounder.

Navigators testing the new method aside of the old will probably not hesitate to accept the new one. As in the use of the sextant, simultaneous observation with either similar or different leads will be a safeguard against error of observation. And so precise and rapid is the sounding under the new method, that simultaneous sounding at bow and stern on an ocean steamer will at once tell the direction and degree of falling off in depth on the steamer's course. Any communication on the subject from those practically versed in matters of navigation will be most thankfully received by the author.

HOBOKEN, N. J., March, 1894.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, June 20, 1894.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 20, 1894

MR. THEO. D. RAND in the chair.

Present, forty-three members and three visitors.

The Actuary submitted the following propositions for amendments to the by-laws of the Institute, recommended for adoption by the Board of Managers at its stated meeting, held Wednesday, May 11, 1894, viz.:

Resolved, That the Board recommends to the Institute an increase of the annual contribution of members to $8, and of the annual payment on second-class stock to $6, and of the fee for life membership to $100.

Resolved, To effect this that the Board recommends the adoption of the following amendments to the existing by-laws of the Institute:

That article ii, section 1, paragraph 4, be amended by striking out the words "three dollars," and inserting in place of them the words "six dollars."

That article iii, section 6, be amended by striking out the words "fifty cents," and inserting in place of them the words "seventy-five cents."

That article iv, section 1, be amended by striking out the words "five dollars," and inserting in place of them the words "eight dollars," and further by striking out the words "fifty dollars," and inserting in place of them the words "one hundred dollars."

That article iv, section 4, be amended by striking out the words "fifty cents," and inserting in place of them the words "seventy-five cents."

The Secretary presented, on behalf of Mr. Henry R. Heyl, the following additional amendments to the by-laws:

ARTICLE XVII.—Amendments. Shall be amended to read as follows:

Amendments to these by-laws to be proposed at any stated meeting, shall be posted upon the notice board by the first of the month. Such proposition, when presented to the meeting, may be considered, and amendments thereto submitted, but action thereon shall be deferred until the next stated meeting, and, pending action, the proposed amendments shall remain posted upon the notice board.

It shall require the votes of two-thirds of the members present to adopt any amendment to these by-laws, except in the case of article ii, relating to capital stock, which cannot be altered unless by a vote of a majority of the stock represented at the meeting.

ARTICLE III.—Members. Shall be amended to read as follows:

SECTION 1. The members of the Institute shall consist of manufacturers, mechanics, artisans, and persons friendly to the mechanic arts, and they may be either annual contributors, life members, permanent members, holders of second-class stock, honorary or corresponding members.

SECTION 3. The privileges of membership in the Institute shall extend only to persons of legal age, who are not in arrears and who shall have signed the charter and by-laws.

ARTICLE IV.—Payments. Shall be amended to read as follows:

SECTION 1. The annual dues of contributing members shall be eight dollars; a life membership (not transferable) may be acquired by the payment of one hundred dollars within any one year, and a permanent membership may be granted to any one who shall, within any one year, contribute to the Institute the sum of one thousand dollars, which membership may be transferred by will or otherwise.

SECTION 5. The annual dues from contributing members may be applied to the current expenses of the Institute, but all moneys received from life and permanent membership shall be vested in the Board of Trustees, the income therefrom only to be applied to the maintenance fund.

On motion of Mr. Chorman, duly seconded, the foregoing amendments were ordered to publication in the manner prescribed in the by-laws, so that they may be formally acted upon at the stated meeting in September next.

The meeting then proceeded to the technical business announced on the programme, namely, the discussion of the subject of the injury to underground metal pipes by electrolytic action due to leakage of the return current from the trolley lines.

The Secretary introduced the discussion by some informal remarks bear-

ing on the history of the subject, and exhibited a number of photographic pictures of iron, gas and water pipes, lead-covered electric cables, etc., from various cities, which showed extensive corrosion, and in some cases actual perforation from this cause. The subject was then discussed by Messrs. I. H. Vail, of New York; Dr. E. J. Houston, E. A. Kennelley, A. Langstaff Johnston, James M. Price, Carl Hering, Wm. McDevitt, and the Secretary. (The discussion will appear in the *Journal* in due course.) Mr. Price exhibited a new rail joint and bond specially adapted to reduce the leakage to a minimum. Mr. Johnston also exhibited the manner of bonding adopted at his suggestion on the Hestonville Electric Railway, in Philadelphia. The Secretary presented, on behalf of Mr. Vail, a fragment of a large water pipe, extensively corroded and perforated by the leakage of current from a trolley line after two and one-half years' exposure to this influence.

The Secretary exhibited and described for Messrs. Wood & Comer, of Philadelphia, an improved multiple distillation apparatus for laboratory use, by which a number of distillations may conveniently be conducted at the same time. In his monthly report, he gave an account, with illustration, of a new product called "cube ice," devised by Mr. Vander Weyde, of London, in the manufacture of which the inventor has taken advantage of the property of "regelation" to make blocks of artificial ice composed of small cubes, which block on being struck with a mallet breaks up into its constituent small cubes. As each of these bears the trade-mark of the manufacturer, the purity of the product can thus be depended upon.

The Secretary gave a *résumé* of the conclusions of the Committee on Science and the Arts on the merits of the American Gas Furnace Company's system of generating and utilizing fuel gas, and on the electrolytic white lead of Mr. Tibbits, of Hoosic, N. Y.

Adjourned.

WM. H. WAHL, *Secretary.*

BOOK NOTICES.

Lectures on Mathematics. Delivered from August 28 to September 9, 1893, before Members of the Congress of Mathematics held in connection with the World's Fair in Chicago, at Northwestern University, Evanston, Ill. By Felix Klein. Reported by Alexander Ziwet. 8vo. Price, $1.50, net. New York and London: Macmillan & Co. 1894.

In this book we have an account of some of the principal advances that have been made in mathematics since 1870, by a man who has contributed largely to this advancement both by his teachings and writings. It is to this latter fact that the great charm of the book is due. For, as is stated in his account of Lie's work, Professor Klein's knowledge of these new ideas has been gained while the ideas were in process of formation, thus giving a mastery of the subjects dealt with, that few who have not grown up with them can ever hope to gain.

The subjects treated are those which are especially characteristic of the period considered. In fact, the book may be said to be an exposition of the

application of geometrical methods to analytical problems. On every page the reader is reminded of the very healthy tendency in modern mathematics of forming a mental image of every step, that is, of assigning a geometrical meaning to every operation.

The matter of the book is divided into twelve lectures and an appendix. Lecture I deals with the work of Clebsch on the Abelian integrals and on the theory of invariants. Lectures II and III treat of the work of Lie on his sphere geometry and contact transformations with reference to their applications to differential equations. Lecture IV, on the real shape of algebraic curves and surfaces. Lecture V, theory of functions and geometry. Lecture VI, on the mathematical character of space intuition and the relation of pure mathematics to the applied sciences. Lecture VII, the transcendency of the numbers e and π. Lecture VIII, ideal numbers. Lecture IX, the solution of higher algebraic equations. Lecture X, on some recent advances in hyperelliptic and Abelian functions. Lecture XI, the most recent researches in non-Euclidean geometry. Lecture XII, the study of mathematics at Göttingen.

The appendix consists of a translation by Professor Tyler, of a sketch by Professor Klein, of the development of mathematics at the German universities.

On concluding the book, the reader cannot help wishing that the number of lectures had been greater, since they are particularly valuable to American readers, as the object of Professor Klein was to supplement the views on these subjects that he found prevalent in America.

Every student of mathematics should read these lectures, since in them we have the ideas of a great mathematician expressed in a way that would be impossible in a systematic treatise. The lectures being informal talks, the individuality of the lecturer had full sway, and the reader feels that he is closer to the author than if the latter were seen only through a mass of formulæ.

A feature of great importance in the book is the numerous references to original memoirs, thus enabling the student to follow in detail the course of development outlined in the lectures. E. A. P.

Tables for the Computation of Railway and Other Earthwork. Computed by C. L. Crandall, C.E., Associate Professor of Civil Engineering, Cornell University. New York: John Wiley & Sons. 1893. Second Edition. Price, $1.50.

In the method for which these tables are intended, the volume of a cutting or of an embankment is first found approximately by averaging the end areas, and then, if desired, a prismoidal correction can be applied. A table of such corrections is given, as is also a table of volumes by averaging end areas.

In this second edition, the text has been entirely revised, and the author has added a proof of the prismoidal formula, a comparison of that formula with others, a formula for correction for curvature, and rules for irregular cross-sections. T.